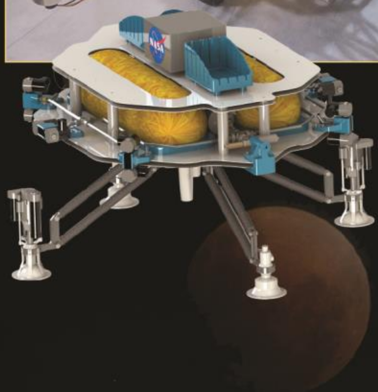
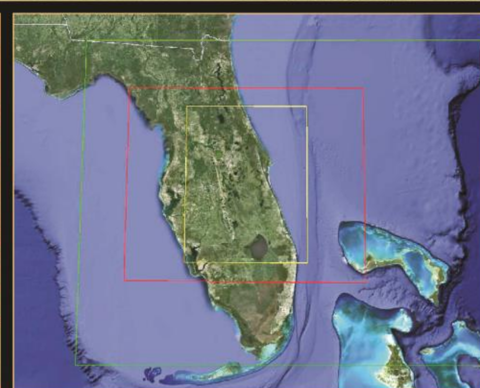
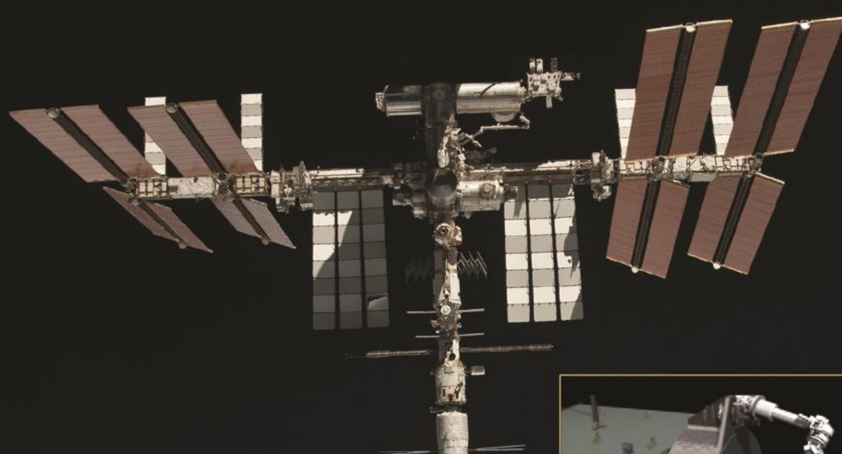
National Aeronautics and
Space Administration

John F. Kennedy Space Center

2016 Strategic Technology Investment Plan



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(Clockwise, from top left)

The launch infrastructure at KSC and Cape Canaveral Air Force Station is being modernized to increase operational efficiency and safety and reduce launch costs. For one of these modernization efforts KSC is developing a capability to help vehicle operators and ground systems engineers automate troubleshooting and analysis, using intelligent systems health management (ISHM) software tools and methods. Functions include anomaly detection, prognostics, fault isolation, and diagnostics using physics-based simulations. A hardware operations set was fabricated and installed in the Launch Control Center's Firing Room 1 for the Ground Systems Development and Operations Program's Exploration Flight Test-1 Flight Following effort.

The Swamp Works Laboratory at KSC modified an Apollo mission design in order to manufacture a geotechnical tool that determines soil cohesion and friction angle. A NASA crew member evaluated the tool during a 120-day Hawaii Space Exploration Analog Simulation (Hi-SEAS), a NASA-funded study conducted in collaboration with the University of Hawaii.

To support Project Morpheus, KSC designed a flame trench that consisted of welded half-inch-thick carbon steel (A36) coated with inorganic zinc paint. Steel cover plates were bolted in place to direct the exhaust and additional aluminum cover plates for fall protection were installed with quick-release pins for easy removal before hot fire. This project was done in partnership with Johnson Space Center to resolve acoustic effects for future Project Morpheus testing.

NASA's Launch Services Program, Ground Systems Development and Operations Program, Space Launch System, and other programs at KSC and Cape Canaveral Air Force Station use the daily and weekly weather forecasts issued by the 45th Weather Squadron as decision tools in their day-to-day and launch operations on the Eastern Range. To improve this capability, the Applied Meteorology Unit (AMU) performed a number of sensitivity tests on the Weather Research and Forecasting (WRF) model to determine its best configuration for operational use. In the future, the AMU will further improve the forecast by implementing an updated version of the WRF model that assimilates local data. This model will run in real time and be available to operational forecasters and launch weather officers.

An Asteroid ISRU prospecting and sampling free-flyer 2.0 and Lava Tube and Crater Extreme Access free-flyer 1.0 Using one or more small free-flyers is a low-risk solution for prospecting on asteroids or other near-Earth objects such as comets. They could fly into Martian or lunar lava tubes to look for resources, map subsurface cavities, and acquire samples. Instead of putting a very expensive main spacecraft to risk in a rendezvous asteroid landing, the small free-flyer can be used as a secondary spacecraft. The Asteroid and Lava Tube ISRU Prospecting (ALTIP) Free-Flyer 2.0 Project leveraged the technology jointly developed by KSC's Swamp Works and Embry-Riddle Aeronautical University in FY 2013 for the Extreme Access free-flyer 1.0 project.

Astronaut Scott Kelly showing a harvest in Veggie, the vegetable production unit on the International Space Station. As NASA embarks on a journey to Mars, learning how to grow and safely eat fresh food will become key to mission success. Veggie was designed to grow appetizing, nutritious, and safe fresh food in space while using minimal resources. Growing crops in space is complicated by the lack of convective flow and fluid microgravity behavior.

Pioneering and settling lunar and planetary surfaces requires the deployment of a propellant management infrastructure that can relieve Earth-based systems from having to lift all the propellant needed for crossing the solar system. Managing the interplanetary infrastructure necessary to generate, store, load, condition, replenish, and offload propellants is one of the biggest challenges of our future in space. KSC has been working with other NASA Centers, industry, and academic institutes to develop the components, materials, and techniques that will create fully functional, space-based propellant management systems.

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2016 Strategic Technology Investment Plan

- **Robotics and Autonomous Systems**
- **Human Health, Life Support, and Habitation Systems**
- **Human Exploration Destination Systems**
- **Ground and Launch Systems**

- Communications, Navigation, and Orbital Debris Tracking and Characterization Systems
- Modeling, Simulation, Information Technology, and Processing
- Thermal Management Systems

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John F. Kennedy Space Center

2016 Strategic Technology Investment Plan

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FOREWORD

Since its inception in 1958, NASA has been at the forefront of scientific and technological innovation, and its investments in space technology have helped make the United States the global leader in space. NASA is moving forward with prioritized technology investments in pursuit of its mission and achievement of national goals. These technology developments create opportunities, markets, and products for industry and academia. The Agency's technology investment strategies address the technical challenges needed to ensure mission success. These efforts in technology development represent an indispensable contribution to a revitalized research, technology, and innovation agenda for the nation; they stimulate the economy and enhance the nation's global economic competitiveness by creating new products, services, businesses, and industries, while also providing high quality, sustainable jobs. This investment strategy maximizes the return on taxpayer dollars to NASA, other government agencies, the private sector, and ultimately, the nation.

Kennedy Space Center's R&T investments focus on its current technical capabilities and its ability to find new and innovative approaches. As the worldwide preeminent launch site, KSC has the experience, persistence, and skill to design and implement innovative techniques, test equipment, and hardware required for long-duration missions and for future in-space and surface operations. KSC's investment strategy aligns with the Agency's priorities with the goal of solving the technical challenges needed to ensure mission success.

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1. STRATEGY OVERVIEW

This investment plan identifies and prioritizes KSC's Research and Technology (R&T) investments to enable or enhance anticipated mission-capability needs. These investments will enhance knowledge, education, economic vitality, and stewardship of the Earth; enable continued and expanded operation of the International Space Station (ISS); prepare us for human exploration beyond low-Earth orbit with the goal of planetary exploration throughout the Solar System and to Mars. These investments could also support science and exploration missions conducted by the commercial space industry and other government agencies, and would result in applications for the general population, including devices that improve health, medicine, transportation, public safety, and consumer goods. This plan ensures that the investments made at KSC align with Agency needs and priorities, capitalizes on KSC's areas of strength, and maximizes the leveraging of available resources and partners to provide the best value return on these investments.

KSC's R&T investments strategy has three elements: the *NASA Strategic Technology Investment Plan* (STIP), the NASA Technology Roadmaps[1], and Techport (http://techport.nasa.gov). (The STIP is the soon-to-be-published successor to the *2012 Strategic Space Technology Investment Plan* (SSTIP), which includes content from the updated 2015 technology roadmaps.) The Center's strategy also considers NASA's Journey to Mars framework.

KSC aligns its strategy with Agency mission directorates, particularly with the Space Technology and the Human Exploration and Operations mission directorates (STMD and HEOMD, respectively). KSC works directly with funding sources at the Center, within the Agency Mission Directorate and Programs, and through other government and nongovernment partnerships.

This plan identifies specific tools that KSC employs to optimize its R&T investments.

KSC's management approach is controlled and guided by a Centerwide Research and Technology Management Board, which is chaired by the Center Chief Technologist and comprises organizational representatives from across the Center. The Technology Management Board and KSC organizations work within a framework of established management principles and apply proven KSC core technical capabilities.

KSC's decades of experience has led it to become world experts in four core Technology Areas, with continued participation and contributions in an additional three supporting Technology Areas. These core and supporting Technology Areas align with the Agency's Technology Roadmaps. Additional R&T work in other Agency Technology Areas (TA) exist at KSC or may be initiated in the future.

The four core KSC Technology Areas (including Agency Roadmap TA numbers) are:

1. Robotics and Autonomous Systems (TA 4),
2. Human Health, Life Support, and Habitation Systems (TA 6),

3. Human Exploration Destination Systems (TA 7), and
4. Ground and Launch Systems (TA 13).

The three supporting KSC Technology Areas are:

1. Communications, Navigation, and Orbital Debris Tracking and Characterization Systems (TA 5),
2. Modeling, Simulation, Information Technology and Processing (TA 11), and
3. Thermal Management Systems (TA 14).

The R&T community at KSC is applying the strategic guidance and methods as described above to current and future investments. These investments aligned with a sustainable exploration vision:

> *"Expand human presence exponentially across the solar system through pioneering capabilities relying less on what we bring and more on what we find."*

This vision capitalizes on the belief that the universe has unlimited resources and tapping into them *in situ* will allow us to expand human space exploration and travel into deep space on long-duration mission because it will free us from our dependence on Earth's resources. The ability to break that dependence will solve the logistical problems we currently have on relying on Earth-based resources. KSC is committing resources today on a wide variety of investigations and technology developments that promote this vision. Together with the Center's innovative capability to focus on practical approaches to tough challenges, future space explorers will be able to travel light, taking from Earth only what is needed to exploit and process materials *in situ,* an ability that will help sustain and expand space exploration.

2. AGENCYWIDE TECHNOLOGY PORTFOLIO MANAGEMENT PROCESS

The Agency's technology portfolio receives top-down direction from the Executive Office of the President via Executive Orders, the *National Science and Technology Priorities*, and the *NASA Strategic Plan*. The portfolio includes technology development programs and projects from each mission directorate and office that develops technology. To optimize the technology portfolio, NASA is working to align its mission directorates' technology investments in order to minimize duplication and lower cost while providing critical capabilities that support missions and longer-term national needs. NASA is accomplishing this by identifying and describing the types of capabilities and performance goals needed by each mission. The goals are compared against the state of the art and potential technologies to determine whether a capability gap exists. Where a gap exists, technologies are identified that could fill this gap.

The STIP is the portfolio management's actionable plan that lays out the strategy for developing technologies essential to the pursuit of NASA's mission and achievement of national goals. The STIP prioritizes the technology candidates within the Technology Area Roadmaps and provides guiding principles for technology investment. The recommendations provided by the National Research Council heavily influence NASA's technology prioritization.

The 2015 NASA Technology Roadmaps[1] considers a wide range of needed technology candidates and development pathways for the next 20 years (2015–2035). The roadmaps (Figure 1) focus on applied research and development activities and include an index of technology candidates that can enable or enhance individual planned missions and conceptual Design Reference Missions (DRMs). Technologies that support NASA's missions may also support science and exploration missions conducted by the commercial space industry and other government agencies. In addition, NASA technology development results in applications for the general population including devices that improve health, medicine, transportation, public safety, and consumer goods.

Figure 1. NASA's Roadmap Technology Areas

NASA's technology investments are tracked and analyzed in TechPort, a web-based software system that serves as NASA's integrated technology data source and decision support tool. Together, the Technology Roadmaps, the STIP, and TechPort provide NASA with the ability to manage the technology portfolio in a new way—aligning mission directorate technology investments to minimize duplication and lower costs, while providing critical capabilities that support missions, commercial industry, and longer-term national needs.

**The Office of the Chief Technologist (OCT) Strategic Integration Office develops policy, requirements, and strategy for NASA's technology development activities in support of the Chief Technologist by coordinating with NASA mission directorates, other government agencies, and external organizations. As part of these efforts, Strategic Integration develops the NASA Space Technology Roadmaps and the* NASA Strategic Space Technology Investment Plan as well as *maintain the TechPort database.*

3. NASA'S JOURNEY TO MARS STRATEGY

NASA's Journey to Mars strategy includes the Evolvable Mars Campaign[2] study and technology needs defined by the Advanced Exploration Systems (AES) Division within the Human Exploration and Operations Mission Directorate (HEOMD).

In recent years, HEOMD and the Science Mission Directorate (SMD) have been working together on what will be a historic merger of direct manifest planning in support of the Agency goals of exploring an asteroid with the goal of putting a human on the surface of Mars.

To meet these goals, the Agency (led by HEOMD and SMD planners) developed a new framework to extend human presence beyond low-Earth orbit, which is in the early stages of planning missions within the framework of an Evolvable Mars Campaign (EMC). Initial missions within the framework will be conducted in near-Earth cis-lunar space and will culminate in extended-duration crewed missions to Mars. This new framework builds NASA's programs and studies, crafted in support of the concept of developing a flexible exploration framework that prepares NASA to explore many possible destinations within our solar system.

NASA followed a principled approach to identifying critical capability needs and a "Proving Ground"[3] approach is emerging to address testing needs. The Proving Ground phase includes a series of missions after the ISS where exploration-enabling capabilities and technologies are developed and the foundation established for sustained human presence in space. This near-Earth phase will increase mission capability while reducing technical risks. The Proving Ground missions also provide valuable experience with deep space operations and support the transition from Earth-dependence to Earth-independence that is required for sustainable space exploration. Figure 2 illustrates these three phases.

New ways to solve problems and technologies emerge almost daily. And though technology is always changing as it moves forward, the Agency's requirement that technology continue to enable the core capabilities remains constant.

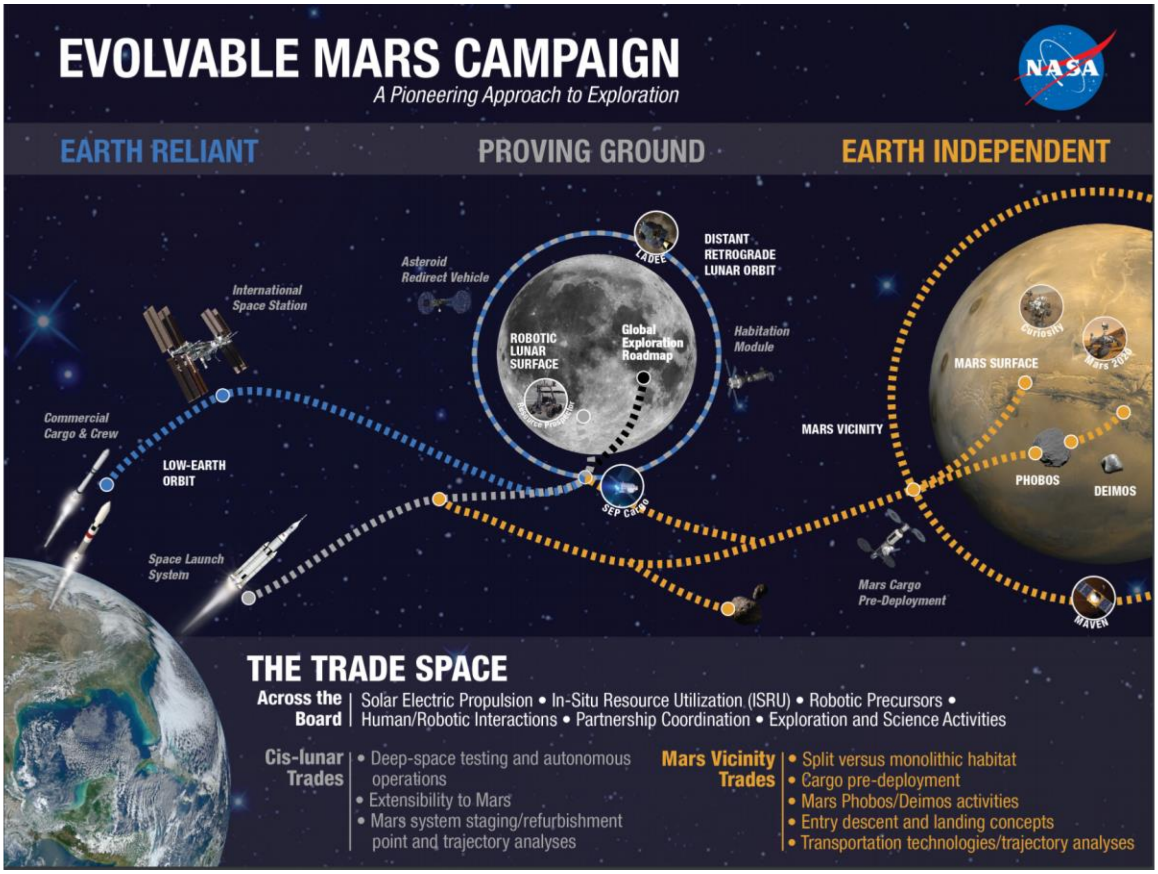

Figure 2. NASA's Evolvable Mars Campaign

NASA created Systems Maturation Teams (SMTs) in late 2013 to identify the capabilities that are needed in each step (phase) for human exploration of the Solar System and on the way to Mars. The SMTs explore capabilities and expose any capability gaps for which technologies must be developed as we move forward. The SMTs comprise subject matter experts from across the Agency who have been involved in maturing systems and advancing technology readiness for NASA. They are defining performance parameters and goals for each of the 14 capabilities, developing maturation plans and roadmaps for the identified performance gaps, specifying the interfaces among the various capabilities, and ensuring that the capabilities mature and integrate to enable future pioneering missions. The subject matter experts that compose each SMT are responsible for understanding their capabilities across all missions and elements within the Evolvable Mars Campaign. The SMTs work closely with the Evolvable Mars Campaign to coordinate capability needs and gaps. A table showing NASA's SMTs working Capability Gap Assessments is in Figure 3.

System Maturation Team
Autonomous Mission Operations (AMO)
Communication and Navigation (Comm/Nav)
Crew Health & Protection and Radiation (CHP)
Environmental Control and Life Support Systems and Environmental Monitoring (ECLSS-EM)
Entry, Descent, and Landing (EDL)
Extra-Vehicle Activity (EVA)
Fire Safety
Human-Robotic Mission Operations
In Situ Resource Utilization
Power and Energy Storage
Propulsion
Thermal (including cryo)
Discipline Team – Crosscutting
Avionics
Structures, Mechanisms, Materials and Processes (SMMP)

Figure 3. NASA'S Systems Maturation Teams for Exploration

NASA's defined capability needs and the steps to close the gaps will be published later this year. The critical near-term gap-closing activities were provided to Agency technology programs and are being integrated into their investment plans.

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4. MISSION DIRECTORATE ALIGNMENT AND DIRECT FUNDING SOURCES

One of KSC's strategic goals is to "Conduct research and develop technology representative of KSC expertise to enable NASA mission success." Through R&T efforts under this strategic goal, KSC supports a variety of Agency customers including SMD, the Space Technology Mission Directorate (STMD), and HEOMD. This includes direct support to KSC's Launch Services Program (LSP) and Ground Systems Development and Operations (GSDO) Program, as well as to other programs with connections to KSC operations.

A considerable amount of the R&T activity comes from NASA mission directorates and programs as directed work and through annual program requirements and guidance statements, to which KSC responds with a plan to engage in the research and technology. KSC is often invited to join large projects or proposals led by other NASA centers or outside organizations as a co-investigator or other type of partner. There are also many other outside calls of research funding opportunities from both government and nongovernment entities, and KSC is often successful engaging in these opportunities.

The following list details primary mission directorates and other funding sources aligned with KSC Research and Technology.

1. Agency Mission Directorates
    - Space Technology Mission Directorate
        - Center Innovation Funds (CIF)
        - NASA Innovative Advanced Concepts (NIAC)
        - Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs
    - Human Exploration Operations Mission Directorate
        - Advanced Exploration Systems (AES)
        - Space Communications and Navigation (SCaN)
        - International Space Station Program (ISSP)
        - Space Life and Physical Sciences (SLPS)
    - Science Mission Directorate
    - Aeronautics Research Mission Directorate (ARMD)
2. Programs at the Kennedy Space Center
    - Ground Systems Development and Operations (GSDO)
    - Launch Services Program (LSP)
    - International Space Station Program (ISSP)
    - Space Life and Physical Sciences (SLPS)
    - Core Technical Capability (CTC)
    - Innovation Research and Development (IRAD)

3. Agency calls through the NASA Solicitation and Proposal Integrated Review and Evaluation System (NSPIRES)
4. Partnering with national laboratories, academia, government agencies, etc.

5. TECHNICAL APPROACHES

5.1 Technology Maturation Opportunities

To succeed in developing new technologies, innovations must advance along the Technology Readiness Level (TRL) spectrum from early-stage basic research to laboratory validation to demonstration in relevant environments. At the lowest levels (TRL 1 to 3), basic principles are observed and documented, technology concepts or applications are formulated, and experimental functionality or proof-of-concept are validated. And at the highest level, TRL 9, the proven systems are used in mission operations. KSC supports this full range of technology maturation with processes, skills, and facilities. (See NPR 7123.1, NASA Systems Engineering Processes and Requirements, for detailed definitions of the TRL scale.)

5.2 Technology Transfer

KSC offers opportunities for industry to partner with NASA on technology development and licenses NASA-patented technology for commercial use. Many technologies require industry partners to further develop NASA laboratory-scale innovations into products that NASA can then purchase to support future missions. By leveraging industry expertise and financial investments under commercialization agreements, NASA can move technology forward more effectively and at less cost to the Agency. See http://technology.ksc.nasa.gov for further information.

5.3 Analog Tests

Operating a technology in a location similar to where it will be in space can be daunting for some researchers, especially when the technology is integrated electrically, mechanically, or in software in a challenging environment with other candidate technologies or systems that are still maturing along the TRL scale.

KSC has many unique mobile logistical and telecommunications capabilities obtained in innovative ways and at extremely low cost that enable KSC and other NASA research investigations to be conducted in remote locations almost anywhere in the world. KSC has served as a partner and regularly enables large teams and KSC participants to execute these complex operations at a minimal cost.

Analog testing, conducted by all mission directorates in different ways, is the short name for a method of formally maturing the technology readiness level of an innovation by testing and demonstrating a breadboard model (TRL 5) or prototype (TRL 6) in a relevant environment. By working with the U.S. Geological Survey, KSC can locate relevant Earth analog test environments for almost any planetary exploration destination in our solar system. These relevant environments might be a desert region, volcanic site, or even the ocean floor.

Scientists and flight mission planners believe good analog geology or mission simulation conditions can be found anywhere, and KSC people and resources have enabled and participated in various research projects throughout Agency mission directorates. KSC is currently working multiple awarded contracts for Agency research projects by first enabling logistical and telecommunications needs for the entire operation and by conducting focused research during the operation.

5.4 Flight Opportunities Program

The NASA Flight Opportunities Program, one of nine programs in the STMD, offers affordable access to relevant space environments for advancing the TRL of new space technologies. Flight opportunities contracts with commercial suborbital flight providers provide technology demonstration flights on a variety of platforms including high-altitude balloons, suborbital reusable launch vehicles, and parabolic aircraft to provide short-duration microgravity exposures to simulate the weightless conditions of space or other relevant environments. There are currently two paths for accessing flight test opportunities: Space Technology Research, Development, Demonstration, and Infusion (REDDI) NASA Research Announcement (NRA) proposals and NASA Directed Payloads. Technologies can compete for flight funding through the REDDI NRA. Awardees receive a grant allowing them to directly purchase flights from U.S. commercial flight vendors that best meet their needs. The REDDI solicitation is biannual. The NASA Directed Payloads path facilitates suborbital flight demonstrations for technologies under development by NASA or other government agencies. Flights are provided by NASA's contracted providers. For more information, see https://flightopportunities.nasa.gov/.

5.5 International Space Station Technology Demonstrations

The ISS was designated as a national laboratory by the 2005 NASA Authorization Act. To fulfill that role, the ISS serves as the premiere platform for space-based science and technology development applications. Its experiments span a large spectrum that include space exposure, materials development, crew health, food supplementation with space-based agriculture, logistics enhancements, and other topics that capitalize on KSC's core and supporting Technology Areas. KSC's traditional roles in assembly, integration, and resupply of the ISS can now be supplemented by new R&T development projects.

5.6 Infusion

The ultimate goal of R&T efforts is to infuse new technologies into operational systems. There are many ways to infuse technology into existing programs and projects in space and on the ground. These opportunities can come from either technology push from innovators or from technology pulls from programs and projects that are seeking game-changing advancements. Opportunities are available today to work with government agencies and on specialized reimbursable projects with industry or academia.

5.7 Tools

This plan identifies specific tools employed at KSC to optimize R&T investments, though the KSC R&T community is not limited to these.

5.8 R&T Proposal Portal

This internal resource for innovators at KSC contains information on research opportunities and developing successful proposals. Website: https://proposalportal.ksc.nasa.gov.

5.9 Technology Portfolio

The Technology Portfolio System (TechPort) provides the NASA community with a single, comprehensive resource for locating detailed information on NASA-funded technologies. TechPort has extensive information that includes descriptions of technologies, images, scientific papers, technology maturity information, and locations where work is being performed. Users can also get export information and create customized reports on selected technologies. Website: https://techport.nasa.gov.

5.10 Tech Transfer/Partnerships

The Technology Transfer Office (TTO) at KSC provides resources for partnering, licensing NASA-developed technologies, and new technology reporting. The KSC TTO can assist with Nondisclosure Agreements, Reimbursable and Nonreimbursable Space Act Agreements, Cooperative Research and Development Agreements (CRADAs), Joint Ownership Agreements, and intellectual property protection. Website: http://technology.ksc.nasa.gov

5.11 Technology Advancing Partnerships Call

The Technology Advancing Partnerships (TAP) Call was developed in 2013 and implemented in 2014. The TAP Call is an annual solicitation released through NSPIRES for potential partners to propose their innovative ideas to develop technology in support of KSC's core and supporting Technology Areas. Under a cooperative agreement, NASA and the partner contribute to the cost of the project. When ideas are further defined to meet specific mission needs, other funding sources from programs and projects may be leveraged.

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6. MANAGEMENT APPROACH

6.1 Organizational

KSC's management approach provides for both top-down controlling and guidance as well as for the appropriate levels of independence at the organizational and individual levels.

KSC R&T is controlled and guided by a Centerwide Research and Technology Management Board (RTMB), chaired by the Center Chief Technologist and comprised of organizational representatives from across the Center. The RTMB considers the strategic investment strategies of the Agency and KSC when approving and managing R&T at KSC, including final authority on all proposals submitted external to KSC. The Board maintains metrics on KSC Research and Technology, using the information to continually assess and recommend adjustments to the Center's investment strategy. The Center Chief Technologist manages the KSC R&T investment strategy for the entire Center. The Board also acts as a pull function, remaining cognizant of opportunities across the Agency, other government agencies, academia, and industry, and then promoting those opportunities that align with KSC's investment strategy. The Board provides a forum to synergize capabilities across the Center and to explore the involvement of external partners to leverage resources, cost-sharing, and be of mutual benefit.

At the organizational level, each Directorate establishes unique R&T strategies that are in-line with KSC's investment strategy and that are suited to their unique capabilities. And at the individual level, researchers and technologists are encouraged to seek out opportunities and build relationships within the Center and across the Agency, other government agencies, academia, and industry. This optimizes Center resources further than what the RTMB can accomplish alone: allowing Center organizations to cultivate areas of expertise while giving individuals a sense of pride and ownership in their respective fields.

6.2 Management Principles and Core Technical Capabilities

The RTMB and Center organizations work within a framework of established management principles and through the application of core technical capabilities.

The following management principles set the framework for KSC's investment in and execution of R&T development:

1. KSC will balance investments across its core and supporting Technology Areas in the roadmaps. Core Technology Areas represent the majority of KSC's R&T development areas though work continues in the supporting Technology Areas and in other Agency Technology Roadmaps. Investments in core Technology Areas include near-term investments necessary to accomplish mission-specific objectives.
2. KSC will balance investments across all levels of technology readiness.
3. KSC will infuse developed technologies into Agency missions whenever possible.

4. KSC will develop technologies through partnerships and ensure developed technologies infused throughout the domestic space industry.
5. KSC will focus on technology development activities that will rapidly produce critical needed capabilities with the potential to revolutionize the way we explore, discover, and work in space.
6. KSC will use a systems engineering approach when planning technology investments.
7. KSC will reach out to the public and share information about its technology investments.

The following proven KSC core technical capabilities enable the investment strategy by optimizing its workforce and providing cost effective and efficient Center services:

1. Acquisition and management of Launch Services and Commercial Crew development
2. Launch vehicle and spacecraft processing, launch, landing, recovery, operations, and sustainment
3. Payload and flight science experiment processing, integration, and testing
4. Designing, developing, operating, and sustaining flight and ground systems and supporting infrastructure
5. Development, testing, and demonstration of advanced flight systems and transformational technologies to advance exploration and space systems

7. KSC TECHNOLOGY AREAS

KSC has decades of experience in R&T development, maturation, and infusion in many of the Agency Technology Roadmap areas. KSC's primary investments are on specific core and supporting Technology Areas that align directly with the Agency Roadmap Technical Areas. But, this does not limit KSC's ability to apply its technical capabilities to other Agency Roadmap Technical Areas. Emphasis on core and supporting Technology Areas will provide focus and clarity of proposals and work, and will leverage synergy of skills and other resources. KSC's core and supporting Technology Areas provide a combination of both push (discipline challenges) and pull (Agency needs) technology development along with clear plans for infusing developed technologies into missions whenever possible, and as soon as possible.

Each Agency Technology Area is broken down into a second- and third-level Technology Area Breakdown Structure (TABS), where individual Technology Candidates (not discussed here) are identified in the fourth level. In this section, KSC core and supporting Technology Areas at the second level TABS are identified and discussed where KSC has relevant experience, is currently engaged, or plans to further mature in the future. The descriptions are derived from the 2015 NASA Technology Roadmaps. The NASA Office of the Chief Technologist's website (www.nasa.gov/offices/oct) has further details.

7.1 Core Technologies

There are four core technology investments at the forefront of KSC's expertise, historical investment, and ability to meet customer and program needs. The KSC Core Technology Areas (TAs 4, 6, 7, and 13) are described in the following subsections.

7.1.1 TA 4 – Robotics and Autonomous Systems

TA 4, Robotics and Autonomous Systems, is broken down into seven areas of capabilities and technologies relevant to NASA's missions over the next two decades, all of which comprise part of KSC's core Technology Area investments.

Table 1. TA 4 – Robotics and Autonomous Systems

TA 4.1	Sensing and Perception	… seeks to develop new sensors, sensing techniques, and algorithms for three-dimensional (3D) perception; state estimation (including sensing and estimation of internal state); onboard mapping; object, event, or activity recognition; and force and tactile sensing.
TA 4.2	Mobility	… pertains to moving from one place to another in the environment, which is distinct from intentionally modifying that environment. Examples include mobility on, into, and above a planetary surface, which spans many forms, such as flying, walking, climbing, rappelling, tunneling, swimming, sailing, and thrusting.
TA 4.3	Manipulation	… pertains to making an intentional change in the environment or to objects that are being manipulated. Examples of manipulation include crew task positioning, moving and handling objects in the

		environment (for example, placing sensors and instruments on planetary bodies), assembling in space and on surfaces, excavating (digging, trenching, drilling), collecting and handling samples, grappling, and berthing. Embodiments of manipulators include arms, cables, fingers, scoops, and combinations of multiple limbs.
TA 4.4	Human-System Integration	… pertains to the manner in which humans, robots, and autonomous systems (for example, spacecraft life support) communicate about their goals, abilities, plans, and achievements; collaborate to solve problems, especially when situations exceed autonomous capabilities; and interact via multiple modalities (for example, dialogue and gestures)
TA 4.5	System-Level Autonomy	… (in the context of robotics, spacecraft, or aircraft) is a cross-domain capability that enables the system to operate in a dynamic environment independent of external control.
TA 4.6	Autonomous Rendezvous & Docking	… pertains to the approach and docking, capture, or berthing of a spacecraft or component to another from up to several kilometers away
TA 4.7	Systems Engineering	… focuses on crosscutting themes for robotics and autonomous systems system-level design methodologies and technologies, interoperability and standardization themes, verification and validation techniques, and engineering tools.

7.1.2 TA 6 – Human Health, Life Support, and Habitation Systems

TA 6, Human Health, Life Support, and Habitation Systems (HLHS), is broken down into five key capabilities necessary to achieve national and Agency goals in human space exploration over the next few decades, of which one comprise part of KSC's Core Technology Area investment.

Table 2. TA 6 – Human Health, Life Support, and Habitation Systems

TA 6.1	Environmental Control and Life Support Systems (ECLSS) and Habitation Systems	… to maintain an environment suitable for sustaining human life throughout the duration of a mission: air revitalization, water recovery and management, and waste management.

7.1.3 TA 7 – Human Exploration Destination Systems

TA 7, Human Exploration Destination Systems (HEDS), is broken down into six technology areas that enable, via human systems integration, sustained human exploration and support of NASA's missions and goals for the next 20 years. These technology candidates will enable a sustained human presence at NASA's exploration destinations, such as Lagrange points, low-Earth orbit (LEO), high-Earth orbit (HEO), geosynchronous orbit (GEO), the Moon, near-Earth objects (NEOs), Phobos, Deimos, Mars, and beyond. Two of these technology candidates comprise part of KSC's core Technology Area investments.

Table 3. Human Exploration Destination Systems

TA 7.1	*In Situ* Resource Utilization	… is the identification, acquisition, and utilization of local resources, both natural and discarded, for useful products and services. The purpose of ISRU is to significantly reduce the mass, cost, and risk of short-term and sustained human exploration by eliminating the need to launch large amounts of consumables, structures, and other items that are required for survival and for completing mission objectives successfully. ISRU also enables self-sufficiency at particular locations, especially destinations far from Earth.
TA 7.2	Sustainability and Supportability	… includes technology candidates required to establish a self-sufficient, sustainable, and affordable human space exploration program.

7.1.4 TA 13 – Ground and Launch Systems

TA 13, Ground and Launch Systems, is broken down into four technology areas associated with Earth-based ground systems and launch. It includes instrumentation systems for wind tunnels; engine test stand support systems; ground systems for sounding rockets and high-altitude balloons; environmental remediation systems; ecological preservation systems; integration, checkout, and servicing systems for launch vehicles and spacecraft; logistical support systems; launch pad support systems; range support systems; weather prediction systems; launch control systems; communications, networking, timing, and telemetry systems; recovery support systems; and returned sample control systems. All four of the TA 13 technology areas comprise part of KSC's core Technology Area investments.

Table 4. TA 13 – Ground and Launch Systems, KSC Core Technology Area

TA 13.1	Operational Life Cycle	… improving technologies that address the operational phase is a very direct way to reduce costs and increase efficiencies, yielding opportunities for new and more frequent missions.
TA 13.2	Environmental Protection and Green Technologies	… technologies that protect systems from environmental effects, remediate and restore the environment from effects of historical programs, preserve the environment, provide environmentally friendly cleaning techniques and energy sources, ensure protection of the destination environment, and ensure sample return containment
TA 13.3	Reliability and Maintainability	… technologies that ensure the reliability and maintainability of systems for integration, checkout and servicing, and launch of launch vehicles, spacecraft, sounding rockets, high-altitude balloons, and ballistic and blended flight systems, as well as horizontal landing of reusable launch vehicles and spacecraft.
TA 13.4	Mission Success	technologies that ensure the success of a mission's launch, landing, and recovery as well as ensure the safety of the astronauts, ground crew, and general public.

7.2 Supporting Technologies

In addition to the four Core Technology Areas, KSC has chosen to focus supporting efforts on three additional areas. Unlike the core areas, the Supporting Areas are predominantly in the "pull" technology development, with the pulling entities providing the investment and managing the infusion. The KSC Supporting Technology Areas (TAs 5, 11, and 14) are described in the following subsections.

7.2.1 TA 5 – Communications, Navigation, and Orbital Tracking and Characterization Systems

TA 5, Communications, Navigation, and Orbital Tracking and Characterization Systems, is broken down into seven technology areas. This TA supports all NASA space missions with the development of new capabilities and services that make missions possible and safe. NASA's space communications and navigation infrastructure provides the critical lifeline for all space missions. It is the means of transferring commands, spacecraft telemetry, mission data, and voice for human exploration missions, while maintaining accurate timing and providing navigation support. Orbital debris can be tracked and characterized by some of the same systems used for spacecraft communications and navigation, as well as by other specialized systems. Six of the TA 5 technical areas comprise part of KSC's supporting Technology Area investments.

Table 5. TA 5 – Communications, Navigation, and Orbital Tracking and Characterization Systems

TA 5.1	Optical Communications and Navigation	… deals with the various technologies required to make communications and navigation with light practical and seeks to take advantage of the virtually unconstrained bandwidth available in the optical spectrum.
TA 5.2	Radio Frequency Communications	… strives to dramatically accelerate techniques in use today for NASA's missions. RF technology development concentrates on getting more productivity out of the constrained spectrum bands that are allocated to space users.
TA 5.3	Internetworking	… deals with the adaptation of the Earth's Internet technology and processes throughout the solar system.
TA 5.4	Position, Navigation, and Timing	… provides all the technologies required to know where spacecraft and targets are, understand their trajectories, and synchronize all systems.
TA 5.5	Integrated Technologies	… deals with crosscutting technologies that work in combination with the other areas to maximize the efficiency of missions.
TA 5.7	Orbital Debris Tracking and Characterization	Tracking and characterizing the "remains" of manmade objects in orbit around Earth is critical to the safe and reliable operation of spacecraft in Earth orbit.

7.2.2 TA 11 – Modeling, Simulation, Information Technology and Processing

TA 11, Modeling, Simulation, Information Technology and Processing, is broken down into four technology areas. This TA spans nearly the entire NASA mission portfolio. Although parts of TA 11 are discipline-specific, most of this TA enables future disciplinary modeling and simulation technologies as found throughout the other technology roadmaps. While the other roadmap efforts address needs from specific domain perspectives, TA 11 focuses on needed advances in flight and ground computing, foundational and crosscutting elements of modeling and simulation, and science and engineering information processing. Three of the TA 11 technical areas comprise part of KSC's supporting Technology Area investments.

Table 6. TA 11 – Modeling, Simulation, Information Technology and Processing

TA 11.2	Modeling	… encompasses technologies needed to support autonomous, integrated, and interoperable modeling capabilities throughout NASA's broad mission portfolio.
TA 11.3	Simulation	… encompasses technologies that enable management of uncertainty and risk across the entire lifecycle of NASA's distributed, heterogeneous, and long-lived mission systems. Improvements in simulation are resulting in increased predictive accuracy and decreased experimentation and expense.
TA 11.4	Information Processing	… encompasses numerous increasingly important capabilities across the entire mission and science data lifecycle that require new approaches for addressing NASA's numerous Big Data challenges. New approaches are required for triaging data with intelligent onboard algorithms and thoroughly analyzing the data using ground-based systems.

7.2.3 TA 14 – Thermal Management Systems

TA 14, Thermal Management Systems, is broken down into three technology areas. This TA crosscuts and is an enabler for most other system-level TAs. As such, the design of thermal management systems inherently requires that nearly all other spacecraft systems for both human-based and robotic spacecraft be considered. Technology development in TA 14 is centered on systems with reduced mass and/or enhanced performance. Increased reliability and survivability in hostile environments are also critical goals. All four of the TA 14 technology areas comprise part of KSC's supporting Technology Area investments.

Table 7. TA 14 – Thermal Management Systems

TA 14.1	Cryogenic Systems	… systems that operate below –150 degrees Celsius (°C) or 123 Kelvin. These include advanced insulation, cryocoolers for both scientific and propellant storage applications, and various heat transfer and insulators or specialized thermal isolation techniques. In TA 14, only the thermal control aspects of cryogenic systems are addressed.

TA 14.2	Thermal Control Systems	… systems that are operating between –150 °C and 500 °C. These systems are broken down by the functions of heat acquisition, heat transfer, and heat rejection and energy storage.
TA 14.3	Thermal Protection Systems	… thermal management systems that operate above approximately 100 °C, although often much higher. TPS technologies are further organized into three subcategories: ascent/entry TPS, TPS modeling and simulation, and TPS sensors and measurement systems.

8. CURRENT AND FUTURE INVESTMENTS

8.1 Alignment with Sustainable Exploration

Current and future KSC R&T investments focus on a comprehensive vision of "sustainable exploration":

> *"Expand human presence exponentially across the solar system through pioneering capabilities relying less on what we bring and more on what we find."*

To accomplish the strategy of NASA's Journey to Mars, we must build stable, reliable systems to support our existence in remote and hostile environments. Our transit to and life in those environments will require the necessary support systems for autonomous operations, including environmental control and life support, propulsion, communications, and the ability to sustain life. To support human life, a continuous supply of food, water, and oxygen will be needed along with systems that will convert waste products into system resources. Providing this continuous supply of resources within a system designed to be as closed loop as possible is an enormous challenge for NASA and our path to Mars.

> *—Traveling Light, Pioneering FAST! — We are traveling light to stay in space for the long haul by starting small, moving quickly, and taking advantage of in situ resource capabilities. —*

KSC believes in a future of unlimited resources and clean energy. The solar system has a billion times more resources than Earth and we will need to tap into those resources to sustain us as we explore outer worlds. So we are traveling light, taking from Earth only what we will need to exploit and process materials available in the solar system. We will reuse materials along the way, eliminating waste streams and optimizing systems performance. Once the spacecraft lands, crew members will use items taken with them, along with surface materials, for construction and radiation protection. Crew members will target water ice in the permanently shadowed regions or buried below the surface, purify it and use it in various ways. The crew will be able to consume this water as well as use it for heat transport or heat rejection. They will also be able to separate the water into hydrogen and oxygen and use it as propellants, fuel cell power generation, or for breathing air. The crew will be able to extract metals such as aluminum, nickel, and titanium to create alloys for making structures and construct vast solar arrays to power exploration as well as beam the power back to Earth. The crew will use waste products such as packaging materials, old spacecraft parts, and food as feedstock for 3D printers to make new tools and parts. Finally, our technology will let us duplicate the Earth's biosphere by using by-products of our presence along with microbiological processes to resupply breathing air, drinking water, and food.

The people that make all of this happen are space pioneers—the explorers who venture into space, as well as engineers, scientists, and all the others who enable the explorers. Pioneers are people with a vision. Pioneers can see opportunities where others may only see obstacles. They see promise where others only see confusion or problems. Being a pioneer means having courage and working hard. Nothing great is accomplished without great effort and great sacrifice.

8.2 The Foundation of KSC R&T

From the beginning of human space flight, KSC has been the place where launch and launch preparations have been conducted. Systems from all over the world arrive at KSC for integrated testing, including launch activities. Working through test protocols in preparation for launch is critical to success and presents many unique challenges. KSC has a long history of developing innovative solutions to critical issues that are exposed during integrated testing of major subsystems. To provide this service for NASA and our international partners, two important elements have been nurtured at KSC: first, the facilities and equipment necessary to conduct this testing and, second, a skilled workforce available for integrated testing, the interpretations of test results, and the development of solutions in real time.

Over time, KSC has continually increased its capabilities in R&T to improve the Center's operations capabilities and its interactions with launch sites worldwide. These capabilities can apply to operations at other destinations as well. For instance, the need to better characterize the effort of rocket exhaust on launch pads and flame trench systems allowed KSC to gain experience in granular mechanics. This experience can also be applied to regolith at launch and landing sites at other destinations such as the Moon and Mars. Applying these skills from developing, operating, maintaining, and improving ground spaceport capabilities can be extended to skills needed for space exploration. At our destinations, we will have to acquire, store, and transfer propellants and life support commodities; operate launch and landing areas; and provide safe environments for our personnel. KSC believes *in situ* resource utilization (ISRU) will be a key enabler for successful, long-duration, distant space exploration. The ISRU capability allows a system of spaceports that will enable commercial and exploration enterprises to move across the solar system.

8.3 Enabling Technologies Aligned with KSC's Technical Areas

KSC CORE TECHNICAL AREAS (TAs 4, 6, 7, 13)

8.3.1 TA 4 – Robotics and Autonomous Systems (Core Technical Area)

The use of robotic and autonomous systems compliments KSC's other Technology Areas by increasing capabilities, minimizing workforce and resource demands, and increasing efficiency through the use of intelligent, automated systems for activities involving a sustainable exploration architecture.

After the system design has been completed, assembled, integrated, tested, verified and validated, and has been finally deployed to the desired location, it then starts the longest and, in most cases, costliest phase of a project: operations and maintenance (O&M). The project life cycle of most systems stretches over a long period of time to maximize the return on investment. To achieve this, systems should be operated and maintained efficiently.

The concept of autonomous operations and maintenance (AO&M) contributes to this efficiency by simplifying, integrating, and automating O&M processes, planning and control activities, and associated assets. Developing systems that operate autonomously with minimal or no human interaction can make the system more safe, cost effective, and beneficial to the project or program.

The goals of AO&M are to reduce O&M costs and schedule impact, reduce personnel involvement in O&M activities to free these resources for mission science and exploration activities, and reduce specialized skills required for personnel performing O&M activities. AO&M systems can also perform some activities better than humans. Rather than working to a schedule of maintenance activities as is typical of human O&M activities, AO&M systems can continuously assess system health, detect any system problem at an early stage and act immediately to solve the problem, and apply predictive assessments rather than reactive approaches to O&M. Focusing O&M resources where they are needed reduces cost, improves resource consumption, and ensures that resources are available when they are needed.

To support outside Earth's environment (whether short or long duration), humans require an infrastructure in place and operational to provide for their needs. Protection from the environment, daily consumables, and mission support equipment to execute their tasks need to be deployed and ready to support the crew. Automation/Autonomy will provide required operation and maintenance of this infrastructure with minimal remote human interaction, well before they arrive, while they are there doing science and exploration, and to support their return to Earth.

NASA is the only organization that routinely operates complex systems at such great distances that communication lags of minutes to hours makes direct teleoperation infeasible. This suggests a critical role for the growing capabilities of robotics and autonomous systems in space exploration. Earth-based research is already demonstrating advances in both, particularly in autonomous vehicles. KSC should explore the use of autonomous systems on the ground, in space, and on planetary surfaces wherever it can provide significant benefits, working directly with human operators in fixed and mobile systems that supplement our capabilities and in autonomous exploration of remote locations where human presence is not feasible and when communication delays prevent real-time decision making.

Future NASA missions will inevitably involve autonomous systems. The goals of reducing maintenance labor and improving reliability and efficiency are the same on the Earth, on the Moon, on Mars, and any other space destination, and these autonomous capabilities for robotics and other systems will improve capabilities for the systems required for exploration operations. With experience in flight and ground operations—both areas where autonomous systems are applicable—KSC is positioned well to be an analog test site for these systems. From its inception, KSC has been tasked by NASA to receive, assemble, test, integrated, and provide launch operations for launch vehicles, payloads, and associated ground systems. Concurrently to that, KSC has provided mission planning and control, logistics, and maintenance functions to the programs. To perform these O&M functions, KSC has developed processes, resources, technical skills, and supporting facilities and systems. Over the years, these functions and activities have been continually improved, optimized, and perfected. Today, KSC has the needed infrastructure, a highly skilled personnel and the required processes to perform this function, and has done significant work with robotic and autonomous systems as described below.

8.3.1.1 Swarming Robotics

Swarming, autonomous mining robots are a focus topic at KSC. Tasking a fleet of small autonomous robots for prospecting and mining resources allows for redundancy and efficiency if the robots work in a coordinated form much as a colony of swarming ants might. Currently, ant behavior-like algorithms are under test and evaluation with simple robots pictured below under a project called Swarmies[10], and the software can then be transferred to mining robot platforms like the

Figure 4. Swarmie Prototype Robots under Test near the Vehicle Assembly Building

RASSOR robot mentioned under the HEDS section of this white paper. Prospecting, functionally similar to geological exploration, would be a logical extension of this activity into a domain where adaptable "intelligent" software will be as important as hardware.

8.3.1.2 System Health Management

To increase launch readiness, reduce system downtime, and reduce the labor required for systems monitoring, KSC is pursuing autonomous systems for commodity management and distribution systems and, specifically, propellant loading. These technologies are applicable to ground operations and are being evaluated and tested at KSC, but they are clearly extensible to other destinations and can be tested using analog test locations. This effort is a joint collaboration with STMD Autonomous Cryogenic Loading Operations and the Advanced Exploration Systems Autonomous Propellant Loading project.

Figure 5. **Autonomous Propellant Loading test bed at the KSC Cryogenics Test Laboratory**

The work occurs at a test bed set up just outside the KSC Cryogenic Test Laboratory's control room. Two large cylindrical storage tanks are connected by a series of highly instrumented pipes. The setup was designed to simulate a ground storage vessel from which to load cryogenic propellant into a rocket fuel tank. Autonomous controls can independently attempt to overcome instrumentation failures by bypassing failed sensors and components or redefining control points. The automation of functions and processes within the system is designed to provide repeatable, reliable loading operations that need only minimal human oversight and intervention. All these features will be even more necessary with limited crew involvement and the time delays of remote destinations to achieve efficient, sustainable launch operations from those destinations.

8.3.2 TA 6 – Human Health, Life Support, and Habitation Systems (Core Technical Area)

To achieve the Agency's exploration goals, reliable systems are needed to support human existence in these remote hostile planets. Our transit to harsh environments and survival there will require the support systems for autonomous operations including environmental control and life support, propulsion, communications, and the sustenance of life. To support human life, a continuous supply of food, water, and oxygen will be needed along with systems to convert waste products to system resources. Providing this continuous supply of resources within a system designed to be as closed-loop as possible is an enormous challenge that needs to be addressed. While enabling deep space exploration, development efforts in human support systems will also have an enormous benefit to life on Earth as we learn to do things that minimize waste and use waste products themselves to produce new resources.

KSC sits on the Merritt Island National Wildlife Refuge and has always had biologists on staff to be good stewards of this environment. To make the best use of these biologists, KSC expertise was applied to life science studies for space flight and, even more specifically, plant biology. Understanding these biological systems facilitates bioregenerative ECLSS approaches using natural processes to begin to close the loop on resource recovery for space flight. These bioregenerative approaches support sustainable exploration because they reduce the need for resupply for ECLSS operations.

NASA can obtain greater return on infrastructure investments (e.g., labs, plant chambers, skilled personnel) by co-utilizing these resource investments for multiple purposes and programs. This expanded usage focus encourages innovative research within the team and important skills are maintained for critical payload processing activities. Methods to produce food, clean water, convert waste materials to needed feedstock, and generate oxygen are all required for exploration. The Agency needs a center where integrated testing of biological and physical chemical system components are conducted with an aim at defining optimum performance for long periods of time and providing needed data for exploration system development.

Figure 6. The ground control unit at KSC for the Veggie unit deployed to the ISS.

KSC will continue providing launch processing service for biological payloads and serve as the Agency's lead Center for plant and associated microbiological research and proposes to expand our activities in the areas of systems testing and maturing integrated food production systems that include plants and microbes as active components. It is highly likely that human space exploration systems will require multiple technologies to achieve optimum performance and biologically based concepts will drive important components. The pathway to this optimum system will require the sequential development of basic science understanding and technologies that take advantage of that knowledge base. Testing these new concepts and systems will establish baseline data for exploration systems. Plants will produce food and oxygen and microbes will break down complex molecules into usable components for further plant growth. The support systems to use these capabilities best within the closed environments of planetary habitats or closed microgravity environments of space flight need to be designed, built, and tested based on well understood science and engineering principles.

NASA currently has a single Veggie vegetable production unit on ISS with LED lighting and the capability to provide astronauts with healthy, appetizing leafy vegetables. However, the water delivery system needs improvement, and the capacity for multiple grow-outs from the same plant growth substrate needs to be tested. When Veggie development and testing is completed, NASA will have acquired the knowledge needed to grow multiple crops with various lighting needs, water demands, and nutrient requirements and will have demonstrated the desired level of performance. The KSC team performing this work is well positioned with skills, equipment, and facilities to continue exploring these critical activities.

Soon Veggie will have a partner that is also being developed through KSC leadership, the Advanced Plant Habitat (APH) on ISS will address important questions about plants in a space environment. Scientists will be able to discern the gravitational effects on plant growth by tightly controlling the environmental conditions of plant experimentation on ISS and in ground controls being performed in KSC's plant growth chambers in conditions of 1 g. Additionally, NASA will be obtaining the knowledge base to drive the metabolic performance of plants being grown in closed microgravity environments and closed 1 g environments.

For NASA to develop and use innovative systems to explore space and inspire the nation's future explorers, we need to continue gaining a broad understanding of closed system environments with biological components. We need to understand how to sustain an isolated crew for long periods of time in transit vehicles and within surface habitats that are biologically and physically closed. Once that understanding is obtained, systems need to be developed and tested to help achieve NASA's exploration goals. The recent success of Veggie for the ISS, for which KSC led the development, as a prototype food production system is a first step on the journey to Mars where large, multicrop production systems will be needed.

Logistical support of future exploration missions will need to address technical challenges associated with food and food production, including closed-system ecology, system mass, power consumption, product shelf life, and storage volume. Long-term operation of exploration systems must resolve critical issues with healthy food, waste management, biological stability of transit and surface habitats, and material reuse. Physical science and system engineering knowledge will be critical for developing systems with biological components.

Plants and humans have a strong relationship on Earth. The benefits of this relationship are ideal for exploration and long-term habitation. Managing the component needs within this complex relationship will require a deep understanding of many elements. For example, light energy (more accurately, photosynthetically active radiation, or PAR) is used by plants to produce nutritious food, clean water, and generate oxygen. It is also used to remove carbon dioxide when grown under the right conditions. Other components of the light spectrum are not needed by plants for photosynthesis but have other uses in a closed system, like power generation and heat.

Like plants, microbial communities are critical to life on Earth. Microbial communities that will develop, stabilize, and evolve within the closed habitats during the mission durations experienced during exploration missions are critical to mission success. These communities can be either positive or negative components within the system as they are on earth and must be managed to achieve the desired results. Among other things, microbes are critical to the digestion of food by humans and for the breakdown of human and plant by-products for reuse.

Explorers and pioneers have a long history of taking seeds and other biological organisms with them on their journeys. Because the exploration logistics train becomes long and challenging, food production upon arrival is necessary for survival. The systems to be used in transit and at the destination, including the needed plants and microbes are key development needs for risk reduction, leading to mission success.

8.3.2.1 Bioregenerative Life Support

Biological approaches to resource recovery and recycling can facilitate closed-loop environmental control systems without using physical-chemical systems and harsh chemicals that must be constantly resupplied from Earth. KSC has considerable expertise in developing these systems.

In addition to performing a wide variety integrated tests as NASA's primary launch and payload processing facility, KSC has been the Agency's preeminent Center for plant research for many years. This research has placed particular emphasis on the incorporation of plants into biological life-support systems for space flight and surface habitats. KSC has also been the leader in developing the regeneration of nutrients and other materials through microbial processes to convert the biological life-support systems to bioregenerative life-support systems.

The expertise, equipment, hardware, and facilities needed to support KSC's role as the primary launch site are also well suited to support this "plant-in-the-loop" research function. KSC develops strategic plans for plant research, manages plant research grants for the Agency from NRA development through grant execution, performs pre- and post-flight testing of plant experiments, and develops test protocols along with Principle Investigators (PIs) so that desired results are obtained in the equipment being used. KSC designs and builds controlled environments to enable plant and microbial research in space. Over the years, the KSC workforce has assisted in preparing hundreds of biological flight experiments for investigators worldwide and played an important role in the success of these investigations.

The KSC plant and biological processing and test areas are ideally suited for integrated testing of components of food production systems as they are developed, and our expertise in plant and microbial science derived from our responsibility to do integration testing before launch is a perfect fit for this exploration effort. KSC has significant experience with plant and biological systems involving water recovery and management as well as habitation (described below). As launch vehicles developed through the efforts of other Centers arrive at KSC for integrated testing and launch, KSC is the logical place to perform ground baseline testing of biological and physical/chemical systems as they are brought together for integrated performance testing.

8.3.2.2 Bioreactors

For the past several years, KSC has been performing baseline studies on the performance of bioreactors in various configurations. Outputs from these reactors are critical components of the closed-loop system needed for exploration. Studies have been conducted on both liquid waste streams and wet/solid waste stream and their transformation into usable products. The startup, steady state operation, and shutdown of these reactors needs to be understood. How biofilms form and operate in these systems and other components in the life support systems is critical baseline information.

Using biological approaches as a step in the water reclamation cycle to pretreat the water before filtration processes would eliminate the need for ionic silver compounds as biocides. Current work in this area includes improving the efficiency by increasing surface area for microbial reactions and evaluating the ability of the system to jump-start after months of dormancy to simulate the packaging and deployment process for payloads launched to ISS.

8.3.2.3 Adding Fish to Begin Water Revitalization

The concept of adding fish to an aquaponics system for growing plants has been in practice for hundreds of years, but it has gotten more attention and has become more practical for hobbyists and horticulturists on Earth with modern technologies. Waste from the fish in these systems provides excellent fertilizer for the plants, and that the fish can add protein to the diet of the crew. A notable demonstration of such a system near KSC is at the Walt Disney World's EPCOT Center, "The Land" Pavilion. Both The Land Disney pavilion and KSC are collaborating with the United States Department of Agriculture (USDA) to improve plant system technologies.

Limited experiments with fish in spaceflight were conducted on the space shuttle with Japanese Medaka fish on STS-65/IML-2. However, more study needs to be applied to their adaptation, their ability to breed, and to the ecological balance of their systems on the ISS through JAXA's Aquatic Habitat facility and potentially other facilities before this approach can be considered for flight systems.

8.3.2.4 Near-Term Food Production for Exploration

KSC currently has several investigations in progress focused at some aspect of the flight or habitat conditions of space exploration.

- Perform baseline studies of other candidate crop like peppers, tomatoes, and onions with other production system requirements.
- Study various plant dwarfing methods to increase crop yield per unit growth volume.
- Study plant response to elevated carbon dioxide levels.
- Develop microbial bioreactors for treating urine and wastewater.
- Study microbial monitoring techniques to provide real-time detection on ISS.
- Study the biological issues of solid wet waste management.
- Transfer knowledge to the next generation through graduate school programs and post doc assignments.

KSC has supported successful plant and microbial flight experiments, performed science investigation, and developed new flight systems. Over the last 25 years, KSC Life Science researchers have published over 500 peer-reviewed journal articles, over 60 book chapters, and numerous NASA technical memoranda. The engineering and technology team has managed, designed, and built some of the most intensely used tools for science investigation in space, including Biological Research in Canisters (BRICs), Kennedy Fization Tubes (KFTs), the Veggie payload, the BioTube payload, and Advanced Biological Research System (ABRS). The scientists and engineers that make up the team also developed the LED lighting system currently being built to re-lamp the ISS and tested the forward osmosis bag currently under consideration as a source for emergency potable water.

8.3.2.5 Mid-Term Food Production for Exploration

While the knowledge base is being defined for specific crops, the next logical step would be to begin food production for crew needs by adding multiple Veggies or next-generation Veggies with an expanded growing area. Veggie currently provides about 0.1 m^2 of growing area. A next-generation, expanded capability would provide 2 m^2 of growing area. This larger interim unit would demonstrate the capability of the system, assess crew interaction time, uncover engineering issues, and cross the valley between a science investigation tool and a production system within habitation units.

Figure 7. The atrium within the Habitat Demonstration Unit during analog testing.

To envision how such a system might work in an exploration habitat, an atrium was developed for plant growth in underused space within the Habitat Demonstration Unit to allow analog testing during Research and Technology Studies (RaTS) in 2011 and 2012.

8.3.2.6 Long-Term Food Production for Exploration — Exploration Future Vision

Once *in situ* production of food becomes accepted as a viable and necessary component of exploration missions, additional effort can be placed on scaling the production unit up to an appropriate size. For transit missions, an attached module could be outfitted for plant production in the 20 m2 range. In addition to food production, it would play a significant role in water purification, carbon dioxide removal, and oxygen production.

A parallel effort to develop surface-based, gravity-dependent systems as separate deployable modules would provide a source of food to explorers living in surface habitats. Science and engineering knowledge gained from the ground-based testing of components of our flight investigations would be directly applicable to surface systems within a gravity field on the Moon or Mars. Food production systems that are predeployed to remote planets with teleoperations would be up and running before human crews arrive.

Early work on this effort has begun through eXploration HABitation (X-Hab) projects within academia. This university work provides two important elements of this development activity. First, the next generation of scientists and engineers are developing skills to address these critical exploration needs while their mentors are transferring current knowledge to them and guiding them in the right direction. Second, these creative teams are developing innovative new concepts and hardware designs. In addition to X-HAB, several of our ISS international partners have ongoing development efforts to use biology as a key element within their life support systems. Future collaborations are also being explored.

8.3.2.7 Using Martian Regolith for Plant Production

Martian regolith as a medium for plant growth has not only been considered in the movie, "The Martian," but it has previously been considered by experts in the field of plant growth as well as experts in regolith at the KSC Swamp Works Labs. Studies on Martian regolith simulant need to be performed to understand the applicability to their usage in plant growth supportability studies for food production, to understand any required perchlorate remediation, and to understand what types and quantity of augmentation (compost and biochar) will be required for Martian regolith in order to ensure adequate results.

8.3.2.8 Deployable Greenhouse Concept

The notion of sending an automated greenhouse integrated module at a remote destination has been studied several times. Two universities explored this concept in the 2014 X-Hab Academic Innovation Challenge, and a similar study was one of the most popular topics of the International Space Apps Challenge in 2013. Obviously this is a topic that resonates inside and outside the NASA community.

Figure 8. KSC Plant Biologist, Dr. Ray Wheeler, pictured in this notional image of a Mars greenhouse

Many challenges are associated with automated greenhouse integrated modules, but the reason this concept is so catchy is that test units are easily replicated on Earth by greenhouses in urban and rural areas in both moderate and extreme environments.

Prior to deploying full scale systems, a prototype could be designed as a pathfinder on a small scale with an inflatable biosphere that is deflated enough for encapsulation for entry on the Moon or Martian surface. It could include a geranium and tropical fish to act as a canary in a coalmine prior to sending people to the destination.

Full-scale systems could be constructed the same as inflatable habitat systems. These could be enhanced by being opaque for natural sunlight collection rather than just reliant on solid-state lighting, and they could be coupled from the ISRU-driven systems for gas generation and capture.

8.3.2.9 Trash to Gas

The overall goal of the Trash to Gas (TtG) task is to develop space technology alternatives for converting trash and other waste materials from human spaceflight into high-value products that might include propellants, power system fuels, and life support oxygen and water. This reuse of discarded materials is a critical component of closing the life-support material loop. The technical approach for TtG is to adapt terrestrial applications technology for use in space, and ensure that the results of this work are available for spin-off applications back on Earth. TtG was a part of the AES Logistics Reduction and Repurposing (LRR) Project between October 2012 and September 2014.

Figure 9. The demonstration unit of the Trash to Gas system in a KSC laboratory.

Escaping Earth's gravity requires powerful and expensive propulsion systems. Maximum use of all materials launched is therefore essential. Leftover food packaging, food scraps, used clothing, tape, paper, and other trash materials can be converted from useless trash to commodities that can be used for energy production or propulsion in crewed spacecraft or rover vehicles. This capability would also address the concern of waste management during long-duration human missions. *In situ* processing of trash is an option to control waste while maintaining a healthful habitat during long-duration missions.

Current human spaceflight missions either carry trash during the entire round-trip mission or discard trash inside a logistic module that is deorbited into Earth's atmosphere for destruction. Affordable human exploration beyond LEO will not include continuous logistic resupply from

Earth, and pressurized volume available for trash storage will be minimal. By converting waste materials that would be useless into propellants or fuels, the need to launch fuel to locations beyond Earth orbit is reduced. The additional cost of delivering mass to locations beyond LEO is even greater; typically over 5 kilograms per day of waste is produced for a crew of four and there is tremendous value to be gained by conversion of waste to fuels.

Converting trash and waste into hydrocarbon fuels, water, and oxygen is a complex process requiring multiple processing steps. Previous experience in this area by KSC principal investigators has provided background data and identified technical challenges that needed to be overcome by the TtG task. The Trash to Gas technology is an example of a technology matured through testing protocols on Earth and is now postured for a flight technology demonstration. The TtG concept has been demonstrated in a laboratory environment and is an excellent candidate for the Combustion Integrated Rack (CIR) of the International Space Station.

8.3.3 TA 7 – Human Exploration Destination Systems (Core Technical Area)

HEDS involve the development of technology to enable successful human activities in space, including a range of activities from surface infrastructure systems to the technology required for ISRU. KSC is positioned well to contribute to sustainable exploration by applying the lessons learned from operations at spaceports on Earth and extends those architecture concepts to the surface infrastructure at other destinations, capitalizing on decades of experience at KSC.

The sustainable exploration vision is all about reaching destinations in the solar system and the unique innovations that are required for those destinations. Much of the focus at KSC is on space resources and, therefore, ISRU is a technology emphasis. ISRU is at the heart of any sustainable exploration approach. KSC is a natural fit for ISRU applications as an extension of its ground operations experience. KSC can apply its experience to the utilization of ISRU to develop surface infrastructure by handling and processing the regolith to extract resources, by transporting and storing the harvested commodities, and by using the regolith to build berms, launch/landing pads, or other structures.

The skills required to extract valuable *in situ* resources — including metals, oxygen, and raw materials from regolith for construction — will reduce the mass required tremendously for exploration. It will also translate to benefits in many areas of Earth where access to resources is limited or difficult.

Extraterrestrial exploration on the Moon or on Mars, for example, requires construction of elements required to support surface activity. We must either deliver all of the necessary components or develop ways to convert native materials into useful components. Transforming *in situ* materials such as regolith or basalt into useful structural elements is a significant way to reduce the mass of materials launched as payload from Earth.

8.3.3.1 Mining Robots

Mining robots will be required to take advantage of ISRU capabilities. Ideally, fleets of small autonomous rovers will be deployed for the mining tasks to provide redundancy and efficiency in their operations.

Figure 10. The RASSOR lightweight excavator.

The Regolith Advanced Surface Systems Operations Robot (RASSOR) is a lightweight excavator for mining in reduced gravity. Accessing craters in space environments may be extremely hard and harsh due to volatile resources — survival is challenging. New technologies and methods are required. RASSOR is a product of KSC Swamp Works, which establishes rapid, innovative, and cost effective exploration mission solutions by leveraging partnerships across NASA, industry, and academia. RASSOR addresses the need for a lightweight (<100 kg) robot that is able to overcome excavation reaction forces while operating in reduced gravity environments such as the Moon or Mars.

A nominal mission would send RASSOR to the Moon to operate for 5 years delivering regolith feedstock to a separate chemical plant, which extracts oxygen from the regolith using H_2 reduction methods. RASSOR would make 35 trips of 20 kg loads every 24 hours. With four RASSORs operating at one time, the mission would achieve 10 tonnes of oxygen per year (8 t for rocket propellant and 2 t for life support).

8.3.3.2 Volatile Extraction Technologies

To be able to use ISRU as part of a sustainable exploration approach, we must be able to extract the volatiles from the regolith and rocks at our destinations.

The Regolith & Environment Science and Oxygen & Lunar Volatile Extraction (RESOLVE) payload is being developed at KSC. The RESOLVE payload is an exploration system designed to be placed on a rover and driven over the surface of the Moon for 9 days to map the distribution of the water ice and other useful compounds seen on previous missions. RESOLVE will drill into the lunar surface and heat the material collected in order to measure the amount of water vapor and other compounds that are present, thus showing how future missions could gather and then use these valuable resources.

Future missions will benefit from this payload's results because it will be more cost-effective to mine water components, fuel, and other compounds at the point of destination rather than transport them from Earth. NASA is packaging the RESOLVE payload in the Resource Prospector Mission targeted for launch in 2020.

Figure 11. The Resource Prospector prototype with its RESOLVE payload searches for a buried sample tube at the Johnson Space Center rock yard in August 2015 (Left). Resource Prospector begins to drill the sample (Right).[6]

Extrapolating this type of technology toward Mars, KSC has been developing technology to extract carbon dioxide provide feed to a Sabatier reactor as part of the MARCO POLO (Mars Atmosphere and Regolith COllector/PrOcessor for Lander Operations). The purpose of the MARCO POLO project is to demonstrate the conversion of Martian CO_2 and water from regolith into methane/oxygen bipropellant on the scale needed for a Mars Sample Return mission and eventually for human rated ascent vehicles.

8.3.3.3 Regolith-Driven Additive Manufacturing

Transforming *in situ* materials such as regolith or basalt into useful structural elements is a significant way to reduce the mass of materials launched as payload from Earth. Considering exploration on Mars, every kilogram of native materials used could save an estimated 11 kg of transportation propellant and spacecraft mass required to launch to LEO.

Regolith-Driven Additive Manufacturing opens many opportunities for explorers. Surface materials like regolith or basalt can be used to produce structural elements that can be interconnected to create launch/landing pads, blast protection berms, roads and walkways, radiation, thermal, and micro-meteorite shielding insulation and structures, equipment shelters, pressure vessels for fluids storage, ablative atmospheric entry heat shields, construction foundations, and other useful structures. Carrying that approach a step further, the additive manufacturing approach could be used for entire structures. If the technology is not certified for pressure vessels for habitation, it could be applied around a hard shell or inflatable habitat structure as a radiation and micrometeoroid protection layer.

8.3.3.4 Metals Extraction

Metals extraction and refinement from regolith can be obtained as a byproduct of ISRU volatile extraction with a minimum of equipment. By applying chemical, electrolytic, and pyrolytic techniques, researchers have been able to extract oxygen from lunar regolith for over a decade. In one of the most simple processes, lunar regolith starts to decompose into oxygen and gaseous metals at 1,200 Celsius under a lunar vacuum. Future research in this area will explore methods to simplify the process by reducing energy/mass requirements, reliance on consumables resources, and dependency on iron-oxide rich regolith. Along with the oxygen production, this process also offers the possibility of producing valuable byproducts including as metals and alloys as well as gases impregnated on the lunar soil such as hydrogen, helium, and argon. The metals and other materials extracted via this process can then be put to use as raw resources for other exploration needs.

8.3.3.5 Regolith Manipulation for Construction

Several ISRU methods are being explored to fabricate pavers, blocks, and other building materials from solid rock on asteroids, moons, and planetary surfaces. Previous work has been performed to create solid building components by fusing regolith. While these endeavors support ISRU-based infrastructure, some bodies in the solar system also contain significant amounts of solid stone that can be quarried or gathered for construction. Conglomerate structures such as walls, berms, and foundations can be constructed by selecting appropriately sized natural stones. For centuries this process has been used across the world over to build structures. Applying this ISRU approach to quarry solid rock components could simplify and accelerate construction of structures on other surfaces.

The Extraterrestrial Regolith Derived Atmospheric Entry Heat Shield project was a NASA Innovative Advanced Concepts project from 2011 to 2012. This NIAC Phase I project was conducted by the KSC Swamp Works Team and investigated an innovative approach to provide heat shield protection to spacecraft after launch and prior to each entry, descent, and landing, (EDL) thus potentially realizing significant launch mass savings. Heat shields fabricated *in situ* can provide a thermal-protection system for spacecraft that routinely enter a planetary atmosphere. By fabricating the heat shield with space resources from materials available on moons and asteroids, it is possible to avoid launching the heat-shield mass from Earth. The phase I effort showed that such structures can protect spacecraft during entry, descent, and landing on a body with an atmosphere. Further studies are required to mature this concept.

8.3.3.6 ISRU-Derived Landing/Launch Pads on Other Surfaces

The composition of the surface regolith on the Moon and Mars can cause problems for landing vehicles for several reasons. Current landing technologies for Mars have allowed the landing of approximately 1 metric ton on the surface of Mars. Many of the current architectures for manned spacecraft to land on the surface of Mars will require 20 to 40 metric tons. With this much mass, the retro rockets used in Mars missions to date are likely to temporarily disperse the regolith underneath the landing site only to have it settle back in upon the lander once the rocket plume is extinguished. That settling could trap the landing vehicle in place. Additionally, the regolith dispersion from the landing plume will impact any other infrastructure within the landing vicinity. To mitigate these risks, KSC has been evaluating technologies and techniques required to develop solid landing pad surfaces to minimize the regolith dispersion. Among the possibilities are deploying a sintering device to melt the surface material in place, the manufacturing of interlocking regolith bricks that could be laid out over the desired landing site, or distributing an additive to adhere to and bind the surface material.

8.3.3.7 ISRU-Enabled Space Power

Solar photovoltaic power is already used by virtually all spacecraft operating inside the orbit and on the surface of Mars and is feasible for some applications on Mars and as distant as Jupiter. Improved performance, reliability, and cost of solar power systems remains important. Manufacturing solar power systems using *in situ* resources has been proposed in the past and would substantially reduce cost for large space-based solar collectors. Such production requires new technology for low-G or zero-G production of highly purified silicon and its fabrication into crystalline semiconductors and more complex assemblies such as solar panels.[7] KSC, with its experience in regolith processing, could investigate the feasibility of *in situ* silicon purification for solar cell manufacture.

A Space Solar Power (SSP) system could be a key piece of technology to enhance exploration capability in the inner solar system. There have been numerous studies on architectures to deploy a Space Solar Power System for Earth, but the difficulties of launching the mass and size required and the complexity of the designs have been challenges to get momentum behind SSP efforts.[8] Utilizing ISRU technologies may provide advantages for manufacturing such elements as the reflecting surfaces and structure. The reduced gravity allows for those elements to be launched into orbit from the Moon or Mars.

8.3.3.8 Lighting Systems

While KSC does not lead Agency habitation activities, this Technology Area is key to the sustainable exploration approach and KSC is pursuing technologies that advance this Agency goal.

KSC has been a pathfinder in solid-state lighting. Initially, expertise was developed in the utilization of LED lighting for plant growth in space to take advantage of the lesser power requirements of LEDs. That expertise was taken forward to benefit the ISS when KSC flew a solid-state light module test article to the International Space Station that was designed to be a drop-in replacement for the problematic fluorescent lights. That successful demonstration has now evolved into an Agency project to replace every fluorescent light on the ISS with solid-state lighting. The new lights will have three modes tailored to help the crew adapt to natural daily rhythms.

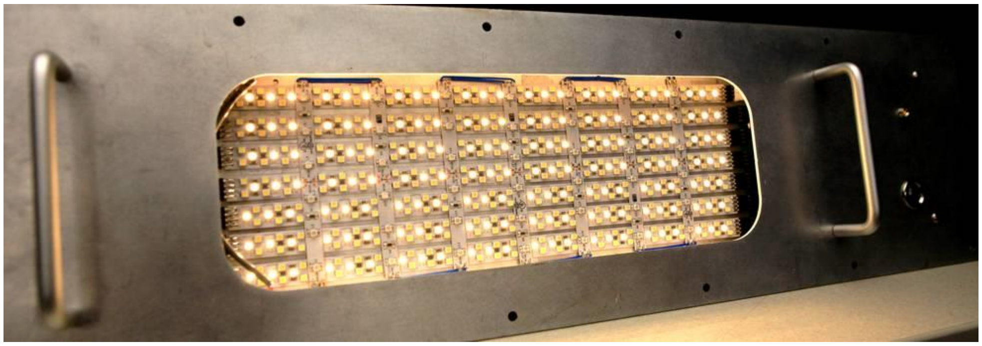

Figure 12. A prototype of a solid state lighting system with both programmable diurnal cycles and an operational data transmission over light capability.

KSC is continuing to develop solid-state lighting with microcontrollers and suites of colored LEDs that allow the lighting modules to be programmed and tailored for varied shifts or normal diurnal cycles. This technology can help the crew achieve better sleep in their habitation environment in transit and at their destination by emulating the natural color waveforms of an Earth day. KSC is also evaluating and developing communications over light systems for potential suitability for space applications.[9] If fully implemented, this type of technology could eliminate significant mass in cable weight for data distribution.

8.3.3.9 Dust Mitigation

Dust mitigation is a significant concern for the health of the crew at the Moon, Mars, and other destinations because of the hazards of ingesting the dust for personnel and for the effects of the dust on equipment. KSC Swamp Works has been developing the Electrodynamic Dust Shield for several years. This system uses a high voltage waveform at very low current to take advantage of electrostatic properties of the regolith to remove it. This technology relies on embedding circuits in the material of interest and has been proven on cloth materials (for spacesuits), on transparent surfaces (for visors, windows, and solar arrays), and on sheets that can be attached to solid surfaces (for hatches, walls, connector housings) and has been tested with Apollo lunar regolith on microgravity airplane flights.

8.3.3.10 Damage Detection Systems

Smart structures can autonomously react to loss of structural integrity or function and react in a manner that allows function to continue rather than going into a “safe mode” or “hibernation” until help arrives. Flexible damage detection systems tested with the Habitat Demonstration Unit analog can be deployed to provide insight into the structural integrity of spacecraft, rovers, habitats, and other systems. They can be manufactured within composite structures or integrated between layers of an inflatable structure to provide autonomous insight into the

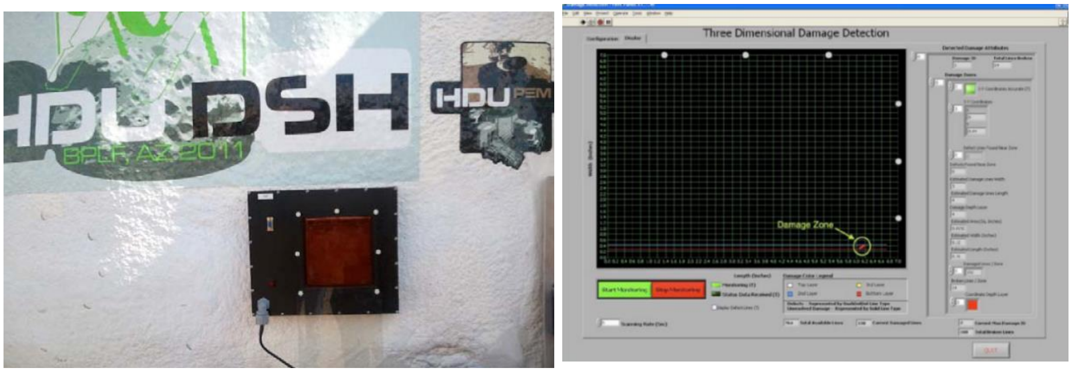

Figure 13. The Flexible Damage Detection system was demonstrated on the Habitat Demonstration Unit and is now being refined for possible flight demonstration.

health of the structure. Several funding sources are currently being used at KSC to cultivate this technology for both ground and space applications. Applied to a habitat structure, the shell can be embedded with smart structures providing assessments of structural health, identifying micrometeoroid impacts or other damage events, and alerting the crew to perform further assessments or affect repairs. This technology has been tested with the Habitat Demonstration Unit for NASA Desert RaTS analog tests and is being applied for ground systems with the Autonomous Propellant Loading project. It is also being pursued as a candidate for flight demonstration to the International Space Station.

8.3.3.11 Multipurpose Materials

KSC is exploring uses for multipurpose materials that can contribute to mission success and support habitation. With weight and space at a premium, the dual use capabilities of these materials is appealing. Graphene production is a research topic at the KSC Swamp Works labs and has promising capabilities for energy storage. Graphene material in the inflatable fabric can be used for power generation with the expansion and contraction and general wave movement of the fabric due to atmospheric conditions and pressurization and depressurization. Metals and plastics may be infused with properties to increase radiation protection, and KSC is currently investigating lightweight, high strength metals with enhanced radiation shielding in a partnership with academia that has aeronautics and aerospace applications. Shape memory alloys with self-healing capabilities have also been a research topic at KSC with the support of Aeronautics Research Mission Directorate and collaborators at KSC. This technology could allow aircraft or spacecraft structural systems to repair inflicted damage.

8.3.4 TA 13 – Ground and Launch Systems (Core Technical Area)

Ground and Launch Systems Technologies contribute to sustainable exploration by improving operations capabilities. These improvements minimize consumables used through the implementation of green approaches for precision cleaning and vehicle fueling. They also reduce recurring and nonrecurring maintenance tasks, recover waste streams, improve situational awareness, and provide more efficient logistical support. Safety improvements can be achieved by improving real-time situational awareness, reducing errors and rework, developments in personal protective equipment (PPE), and improving ground safety tools.

Operations guide our technology development at KSC. KSC focuses Ground and Launch Systems Technologies research on commodity production, distribution, and conservation and integrated refrigeration and storage of cryogens. Additionally, KSC uses analogs and conducts activities as a test bed for exploration architecture. The implementation of this research offers many benefits to KSC that include reducing launch costs through applied technologies that infuse automation, conservation, and situational awareness. Reducing commodity losses and costs over long-term operations can save significant resources. Testing concepts such as propellant plants for destination systems using KSC as an analog for those sites takes advantage of the experience and capabilities of the KSC and allows for other opportunities to test future systems in an analog test environment. Finally, developing and testing common standards for reservicing operational spacecraft will enable resource sharing, open exploration architectures for ISRU technologies, and reduce unique infrastructure for ground and destination servicing systems.

8.3.4.1 Commodity/Propellant Conservation

Helium is a nonrecurring natural resource of finite supply that is critical for space exploration activities requiring the use of cryogenic propellants. Today's launch systems require tremendous amounts of helium to safely process and launch vehicles, cargo and humans into space. As a reference, helium usage during the Shuttle Program was approximately one million standard cubic feet of helium (1 mmscf) per week during nonlaunch activity. For Shuttle launch activity, usage would climb dramatically with another 1 mmscf. Delta IV Heavy launches require an additional 2 mmscf. SLS helium requirements will be similar, with an expected usage of 4.5 mmscf for a planned launch countdown activity.

Helium prices continue to rise well above inflation rates as world demand grows and new sources of helium (helium comes from natural gas sources that have a high (0.3%) concentration of helium in the raw mined gas stream) have not kept up with demand. Helium costs are projected to increase 8% to 10% per year for the foreseeable future.

To realize long-term cost efficiency and reduction of helium usage across the Agency and launch provider enterprise, KSC (in partnership with Stennis Space Center) should take a leadership role in developing technologies that reduce the use of helium, recycle helium from our processing waste streams, or eliminate reliance on helium in our engine testing and launch processing activities.

8.3.4.2 On-Site Production, Storage, and Distribution Fluids

Present and future launch vehicles at KSC and around the world use cryogenic propellants that use oxygen as the oxidizer in concert with cryogenic methane or hydrogen or storable kerosene derivatives as the fuel. To acquire cryogenic commodities for use at KSC, they are purchased offsite and transported to the launch site. Unfortunately, these manufacturers are a considerable distance from KSC, leading to significant transportation costs and high loss rates. For example, LH_2 delivered to KSC comes from McIntosh, Alabama, about 650 miles away. The transportation costs add about 40% to the cost of the commodity, and transportation and transfer losses are 20% to 25% after the 14-hour journey to Launch Complex (LC) 39B.

The availability of cryogenic commodities to support multiple launch attempts becomes a concern for large vehicle systems because of these long travel distances and limited roadable tanker resources. For example, support to enable a second attempt after a scrubbed SLS launch will be supported by building LH_2 inventory at the Delta Rocket Launch Pad on neighboring CCAFS (SLC37B). For weeks prior to the scheduled SLS launch, the LH_2 supplier's tankers will transfer about 275,000 gallons to LC39B.

For long-term cost efficiency, KSC should take the leadership role in developing technologies that can reduce or eliminate propellant losses and increase availability of commodity to support launch operations. This includes technology development and demonstrations to enable local, modular propellant production capability, zero-loss storage and transfer, and increased thermal efficiency of storage and distribution systems. These efforts mimic technologies, processes, and architectures needed for sustained human presence beyond earth and therefore serve as an analog demonstration environment for future exploration systems. These commodities can be made from multiple feedstocks including oxygen, nitrogen and CO_2 from the air, oxygen and hydrogen from seawater, hydrogen and methane from coal or natural gas, and methane from hydrogen and CO_2. The capture of CO_2 would also be a technology contribution to the reduction of greenhouse gases.

8.3.4.3 Integrated Refrigeration and Storage of Cryogens

The energy efficient and cost effective storage and transfer of cryogens including liquid hydrogen (LH_2), liquid oxygen (LO_2), and liquid methane (LCH_4) is a vital part of paving the way for the use of exploration and long-term presence in the solar system. Technology development challenges include integrated refrigeration systems and thermal insulation systems. Improved approaches to integrated refrigeration systems will enable cost savings and lower risks. Advanced thermal insulation systems using the latest materials, vacuum technology, and heat transfer analysis will provide solutions for cryogenic storage and transfer.

The long-term sustainability and operations costs of improvements in the production, distribution and storage systems for cryogens and other commodities used at KSC will lead to reduced ground operations costs, and using KSC as an exploration analog site will serve as a pathfinder to operations concepts at other exploration destinations.

8.3.4.4 Launch Infrastructure — Earth Analogs

Because ground operations at KSC provide unique expertise in surface systems at other destinations, all operations at KSC serve as analogs for exploration. Taking that ability further, one of KSC's major contributions moving forward could be to provide a surface systems outpost analog site to use as a venue for technology infusion and demonstration.

KSC's experience in propellant handling, storage, and transfer provide expertise in being able to demonstrate an ISRU propellant production prototype plant. This plant could supply fuel for return vehicles as well as commodities for fuel cell driven rovers or cold gas thruster driven hoppers for resource initially. These types of test activities can be performed in an outdoor rock yard, but eventually the agency will have to move to analog test sites with more fidelity with reduced pressure and regolith.

Moreover, analog activities could be hosted at KSC in existing or new facilities that are scaled as appropriate for demonstration purposes. At a reduced scale, complete systems could be demonstrated in a vacuum chamber emulating the thin atmosphere at Mars or the higher vacuum at the Moon or asteroids. Combining reduced-scale vacuum chamber tests with a program of full-scale demonstrations in outdoor rock yards may be able to yield a set of test results that will validate the architecture through a combined set of analog tests. The series of Desert RaTS tests done in 2009 through 2012 near Flagstaff, Arizona, are typical of the type of test that can be performed as a component of an analog test program. Focused and repetitive tests using analog test sites will allow for confidence in future missions and add value to both ground operations at KSC and spaceports around the world but also to destination surface systems.

Figure 14. Habitat Demonstration Unit and Space Exploration Vehicles pictured during 2010 Desert RaTS analog testing

8.3.4.4 Commonality in Interfaces to Enable Resource Sharing

With the proliferation of government and civil spacecraft, there is growing potential for cooperative activities and reutilization of these vehicles. Currently, there is no organized effort to align commodity types or connections among these vehicles. A set of standards for resource transfer interfaces should be established and demonstrated to allow vehicle servicing at the launch site and at other destinations using ISRU-derived propellants for commodity transfer. Without the establishment of common interface standards for launch site, in-flight, or destination resupply for space vehicles, these activities will not reach their full potential or establish potential commercial markets to provide services such as propellant supplies.

The ability to perform this resupply with ISRU-derived propellants will allow reservicing vehicles with this standard and with lower long-term costs when launched from lower gravity wells at destinations including Moon, Mars, and asteroids. Future operations on the surface of the Moon or Mars will require the ability to permanently or temporarily connect one surface element to another to share power and transfer fluids and data. This is of particular interest to transfer propellants between an ISRU propellant production facility and the ascent vehicle or surface rovers that require those fluids to perform their jobs. Spacecraft may be designed to be reserviced in-flight via propellant depots or by other space vehicles, thus extending their useful lives and reducing repetitive infrastructure costs for the space community.

KSC SUPPORTING TECHNICAL AREAS (TAs 5, 11, 14)

8.3.5 TA 5 – Communications, Navigation and Orbital Tracking and Characterization Systems (Supporting Technical Area)

Communications, Navigation, and Orbital Tracking and Characterization Systems support all NASA space missions by developing new capabilities and services that make missions possible and safe. NASA's space communications and navigation infrastructure provide the critical lifeline for all space missions. It is the means of transferring commands, spacecraft telemetry, mission data, and voice for human exploration missions, while maintaining accurate timing and providing navigation support. Orbital debris can be tracked and characterized by some of the same systems used for spacecraft communications and navigation, as well as by other specialized systems.

Advancements in communications and navigation technologies will allow future missions to implement new and more capable science instruments, greatly enhance human missions beyond Earth orbit, and enable new mission concepts. This will lead to more productivity in science and exploration missions, as well as provide high-bandwidth communication links that will enable the public to be a part of NASA's exploration and discovery programs. Orbital debris tracking and characterization systems can be improved using radio frequency and optical techniques similar to those used in communications and navigation systems, as well as other dedicated systems, and will make crewed and robotic missions in Earth orbit safer for longer durations.

8.3.6 TA 11 – Modeling, Simulation, Information Technology and Processing (Supporting Technical Area)

Modeling, Simulation, Information Technology, and Processing impacts most of the Technology Areas. The foundational modeling, simulation, information technology, and processing technologies in this area enable the development of application-specific modeling, simulation, and information technologies as found throughout the other technology roadmaps. These technologies also form the base of Agencywide capabilities needed to meet the ever-increasing modeling, simulation, information technology, and processing demands of NASA's missions in exploration, science, and aeronautics and are an important component of solutions to NASA's greatest challenges.

KSC joined or led Agency efforts in these areas beginning with the engineering environment studies in the late 1990s through the overall leadership of modeling and simulation for the Constellation Program. KSC strengths include massive synthetic environments, collaborative engineering, collaborative operations, and complex system visualization. These capabilities allowed KSC to develop new and efficient systems, rapidly plan (and replan) contingency operations, and dramatically increase customer involvement in the design process. All of these capabilities have been shared across NASA and with other government agencies. Today KSC brings this expertise to the EMC modeling and simulation team, leading efforts in virtual environments, information representation, and system integration.

The Research and Development portfolio includes standard-based distributed visualization, persistent data types, data interoperability across tools and systems, human-toosystem interfaces, complex system representation, system engineering tools, standards for multi-decadal data, and complex system visualization. Efforts have created powerful visual environments that support development, operational planning, are portable, protect intellectual property, allow international partner participation, incorporate huge data sets (VAB, with Orion, SLS, ML, LAS, and work stands) and will soon support architectural development and maturation for the Mars surface systems and activities.

8.3.7 TA 14– Thermal Management Systems (Supporting Technical Area)

Thermal Management Systems is a crosscutting Technology Area where KSC has a strong history in supporting technologies. The designs of thermal management systems inherently require that nearly all other spacecraft systems for both human-based and robotic spacecraft be considered through an integrated approach. The fundamental goals of a thermal management system are to maintain temperatures of a sensor, component, instrument, spacecraft, or space facility within the required temperature limits, regardless of the external environment or the thermal loads imposed from operations. KSC has been and will continue to make significant contributions to NASA's technical challenges in thermal management.

KSC actively leads and supports in passive and active thermal control systems and integration and modeling for cryogenic systems. An excellent example of KSC strategic investment is our one-of-a-kind cryogenics test laboratory. The lab's capabilities (research development and testing) and a Ground Operations Demonstration Unit for Liquid Hydrogen (GODU-LH_2) are being developed under the AES program and will demonstrate active thermal control of the propellant state by direct addition and removal of heat using a cryocooler.

The Cryogenics Test Laboratory at KSC has a strong history in the development of storage and transfer of cryofuels, including hydrogen and methane; in the area of thermal insulation systems, the development of insulation test cryostat instruments for thermal conductivity and cryogenic-vacuum thermal performance; and in the development of new international standards on cryogenic insulation (ASTM C1774 and ASTM C740) with industry partners worldwide. Technology focus areas include thermal insulation systems, integrated refrigeration systems, advanced propellant transfer systems, novel components and materials, and low-temperature applications. KSC’s heat transport portfolio transport by partnerships, infusion, and potential technology transfer in novel structural-thermal insulating composite materials and designs will enable new architectures and cross-cutting advancements in many industries from energy to transportation to construction to manufacturing. KSC’s work in Cryo-Coupled Thermal Protection Systems (TPS) may contribute to the Agency’s TPS Technology Areas area, and KSC’s investigations into structural-thermal insulating composites could figure into advancements in the Agencywide thermal controls area.

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10. CONCLUSIONS

Following the Agency's approach to accomplish mission objectives with emphasis on research and technology development, KSC has set the goal of conducting research and developing technology that are representative of KSC's expertise to enable NASA mission success. KSC has aligned its investment strategy with the Agency's technology portfolio management process; the Agency's Journey to Mars strategy; and directly with the needs of mission directorates and programs. KSC R&T uses a set of proven technical approaches and tools, and functions under a well-structured management approach.

KSC has identified four core Technology Areas that have a strong history at KSC, and these areas represent the majority of KSC's R&T investment. The Center also is involved in specific supporting Technology Areas. KSC R&T investments align with these Technology Areas and with the KSC vision for "sustainable exploration."

This plan provides the strategy to ensure work at KSC aligns with Agency needs and priorities, capitalizes on areas of strength at KSC, leverages available resources, and partners to provide the best value for investments in R&T.

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APPENDIX 1. CURRENT KSC RESEARCH AND TECHNOLOGY PORTFOLIO

Listed here are KSC's active projects in Techport, Technology Portfolio System. These are projects where KSC is identified as the Lead Center. This snapshot report was made April 15, 2016. A real-time report can be generated through https://techport.nasa.gov. The list of active projects follows the directions here on generating a report.

To generate a report, go to that webpage and click REPORTS at the top of the page and follow steps 1, 2, and 3 as shown.

STEP 1

Status
Program, Project, and Element Status: ☑ Active
Public Tab Release Status: ☑ Released

Date
⦿ Active during any date range

Activity:
⦿ Select All

Technology Areas (Roadmaps):
⦿ Select All

Mission Directorates and Offices:
☑ Acting as Responsible Mission Directorate/Office
☑ Providing Funding/Resources
⦿ Select All

Programs:
⦿ Select All

NASA Centers and Facilities:
☑ Acting as Lead Center/Facility
☑ Acting as Supporting Center/Facility
☑ Providing Funding/Resources
⦿ Kennedy Space Center (KSC)

Locations Where Work is Performed:
⦿ Select All

Click **Search** at the bottom of the page. The results are shown in either **Standard View** or **Expanded View**.

Click on REPORTS at the top again. Step 1 reads "You have already completed a search," which signifies that your search parameters are saved. To change the search parameters, click **Search for programs, projects, and technologies** again to run a new search.

STEP 2

a. Click **Return to search results and make selections.**

b. On the **Search Results** page, click **Select All** to select all of the projects. Or, you can select only certain projects by clicking on their check box.

STEP 3

a. Click **REPORTS** again at the top of the page. The link returns you to the page with the steps. Step 3 gives you a choice on the types of reports you can download.

b. On the far-right column, in the tab General Information, Download All Attributes Excel workbook, click **Download**.

c. In the pop-up window, select the check boxes for all of the fields you want to include in the report to be exported to a Microsoft Excel file.

d. When you are done with your selections, click **Next**.

e. From the Export pop-up window, enter a filename and click **Export**.

f. A pop-up window at the bottom of the screen will ask if you want to open or save your file. Choose **Open**, **Save**, or **Cancel**.

g. Select **Open**.

You can now save the file to a directory.

APPENDIX 2. ACTIVE PROJECTS IN TECHPORT

TechPort ID	Item Title	Status	Abstract	Responsible Mission Directorate	Lead Center or Facility
10804	Technology under Moon and Mars Analog Missions Activities (MMAMA) Project	Active	NASA Analog Missions research addresses the need for integrated interdisciplinary field experiments as an integral part of preparation for planned human and robotic missions to asteroids, the Moon, and/or Mars. This program addresses NASA's planetary science goal to "ascertain the content, origin, and evolution of the solar system, and the potential for life elsewhere" by preparing us to maximize science in the human exploration of planetary bodies.	Science Mission Directorate	NASA Headquarters
13650	Advanced In-Space Propulsion (AISP): High Temperature Boost Power Processing Unit (PPU) Project	Active	The end goal of the High Temperature Boost Power Processing Unit (HTB-PPU) Project is to develop, demonstrate and deliver a new technology enabled, high temperature operational, modular and power-scalable 10–80kW PPU that significantly reduce the mass and volume of power system that significantly advanced current capability and performance over existing PPU technologies and reduces the mass and volume of power system. The end goal of the High Temperature Boost Power Processing Unit (HTB-PPU) Project is to develop and demonstrate a modular, high efficiency and power-scalable 10–80kW PPU for use with high power Hall thrusters. The new PPU will be use new Silicon Carbide (SiC) components to be capable of operation at temperatures 2× beyond current state of the art. The combination of improved efficiency and increased operating temperatures can significantly reduce the mass and volume of power and thermal systems for 300kW-clase solar electric propulsion spacecraft.	Space Technology Mission Directorate	Langley Research Center
13603	In-Space Robotic Servicing (ISRS) Project	Active	This project advances the state of robotic technology to enable the routine servicing of satellites that were not designed with servicing in mind, including observatories and space infrastructures.	Space Technology Mission Directorate	Goddard Space Flight Center

TechPort ID	Item Title	Status	Abstract	Responsible Mission Directorate	Lead Center or Facility
17547	Human Robotic Systems (HRS): Rover Technologies Project	Active	The Rover Technologies theme area within HRS will develop technologies focused on the Resource Prospector (RP) mission. The RP mission is an Advance Exploration Systems (AES) project managed out of ARC. The mission will be a cost constrained Class D mission, where risks will be understood, but not necessarily bought down. As the project currently is being executed, the surface element (rover and payload) will be NASA provided and the lander will be contributed. The rover element for RP will be executed as a partnership between Space Technology Mission Directorate (STMD) and AES. STMD's investment will primarily be maturing systems for the rover and controlling the rover through TRL 6 during FY2015–2017. The rover technologies serves as rover technology development effort for the RP rover element. The Rover Technologies theme will leverage previous investment from STMD in robotics. For the most part, these technologies will need adaption for the RP mission requirements.	Space Technology Mission Directorate	Johnson Space Center
32948	Autonomous Propellant Loading Project	Active	The AES Autonomous Propellant Loading (APL) project consists of three activities. The first is to develop software that will automatically control loading of cryogenic propellant into launch vehicles to ensure safe and successful propellant loading. The second part of the project is to build a system to demonstrate zero-loss cryogenic propellant (liquid hydrogen) transfer and storage, hydrogen liquefaction, and liquid hydrogen densification. The third area is developing systems to develop technologies to monitor the status of composite tanks used to store cryogenic propellants to ensure they are safe to use. This project builds on the AES Integrated Ground Operations Demonstration Unit (IGODU) project.	Human Exploration and Operations Mission Directorate	Kennedy Space Center

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11722	Ka-Band Objects: Observation and Monitoring Project	Active	NASA has embarked on a path to implement a high power, higher resolution radar system to: • Track Near Earth Objects (NEOs)—asteroids and comets—100,000 times more accurately than optical telescopes, as part of a system to defend the Earth from major impacts. • Characterize the size, shape, spin rate, and surface properties of these NEOs to determine which are suitable for eventual visits by crews or mining companies. • Track orbital debris to ensure crew and spacecraft safety. The path to the high power radar will take evolutionary steps to lead to the revolutionary capability. The first step is KaBOOM.	Human Exploration and Operations Mission Directorate	Kennedy Space Center
32722	Visible-Light-Responsive Catalyst Development for Volatile Organic Carbon Remediation Project	Active	Photocatalysis is a process in which light energy is used to “activate” oxidation/reduction reactions. Unmodified titanium dioxide (TiO2), a common photocatalyst, requires high-energy UV light for activation due to its large band gap (3.2 eV). Modification of TiO2 can reduce this band gap, leading to visible-light-responsive (VLR) photocatalysts. These catalysts can use solar and/or visible wavelength LED lamps as an activation source, replacing mercury-containing UV lamps, to create a “greener,” more energy-efficient means for air and water revitalization. Recently, KSC developed several VLR catalysts that, on preliminary evaluation, possessed high catalytic activity within the visible spectrum; these samples out-performed existing commercial VLR catalysts. Project Goals: Develop rugged reactor test bed for catalyst testing with exchangeable light sources. Optimize KSC-developed VLR-catalysts to treat recalcitrant trace contaminants found in closed-loop air systems such as ISS. Advance TRL to align with AES goals for FY2016–2017 scale-up testing.	Space Technology Mission Directorate	Kennedy Space Center
11874	In-Space Manufacturing Project (prior to	Active	The In-Space Manufacturing (ISM) project is responsible for developing the manufacturing capabilities that will provide on-demand, sustainable operations during NASA Exploration Missions (in-transit	Human Exploration and	Marshall Space Flight Center

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	FY2015: Additive Manufacturing Technology Development		and on-surface). This includes testing and advancing the desired technologies, as well as establishing the required skills and processes for the processes (such as certification and characterization) that will enable the technologies to become institutionalized. The key capabilities being developed in ISM to support this “make it, don't take it” approach include developing a 3D printing Fabrication Laboratory (“FabLab”) that can manufacture parts in space using multiple materials, as well as the ability to embed printed electronics, in-space recycling of printed parts and other materials such as packaging in order to reduce mass and waste, and manufacturing structures externally in space. In 2015, the ISM project made history by sending the first 3D printer to ISS and manufacturing the first parts ever in space. This was a critical first step in demonstrating additive manufacturing in microgravity. Note: Prior to FY2015, this project was named the Additive Manufacturing Technology Development project.	Operations Mission Directorate	
9464	Novel Instrumentation for Lunar Regolith Oxygen Production Facilities, Phase II Project	Active	In this SBIR effort, Los Gatos Research (LGR) proposes to develop, test and deploy three novel compact, rugged and easy-to-use multi-gas analysis instruments, based on tunable diode laser absorption spectrometry and a patented cavity-enhanced laser absorption-based strategy called Off-Axis Integrated Cavity Output Spectroscopy (Off-Axis ICOS), for monitoring and control of extraplanetary regolith processing and oxygen production. The instruments will also prove useful for *in situ* surface analysis. The first instrument (Instrument #1), based on fast extractive sampling, will record measurements of several important gas-phase constituents in regolith processing facilities with extraordinarily high sensitivity, accuracy and specificity in real time. This instrument will integrate directly into NASA's hydrogen and carbothermal reduction test facilities at Mauna Kea, Hawaii. The measurement quantities of interest include the concentrations of HF, HCl, H2S, O2, H2, CH_4, CO, CO_2, H_2O, and H_2O isotopes (H_2HO or HDO	Space Technology Mission Directorate	Johnson Space Center

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			and H218O). The second instrument (Instrument #2) will provide measurements of H_2O concentrations and gas temperature directly in the high temperature reactive flow and prior to hydrolysis. The third instrument (Instrument #3) will provide accurate quantification of the aforementioned gases in a compact, low-power form factor suitable for integration into the Regolith and Environment Science and Oxygen and Lunar Volatile Extraction (RESOLVE) project. This analyzer will be used to study both thermal desorption and hydrogen reduction of extraplanetary regolith.		
32728	Voxel Advanced Digital-manufacturing for Earth & Regolith in Space Project	Active	A voxel is a discrete 3D element of material that is used to construct a larger 3D object. It is the 3D equivalent of a pixel. This project will conceptualize and study various approaches in order to develop a proof of concept 3D printing device that uses regolith as the material of the voxels. The goal is to develop a digital printer head capable of placing discrete self-aligning voxels in additive layers in order to fabricate small parts that can be given structural integrity through a post-printing sintering or other binding process. The quicker speeds possible with the voxel 3D printing approach along with the utilization of regolith material as the substrate will advance the use of this technology to applications for *In situ* Resource Utilization (ISRU), which is key to reducing logistics from Earth to Space, thus making long-duration human exploration missions to other celestial bodies more possible.	Space Technology Mission Directorate	Kennedy Space Center
18104	New Flexible FR Polyurethane Foams for Energy Absorption Applications, Phase II Project	Active	Project involves development of new flexible FR polyurethane (PU)insulation foams through a nontoxic environmentally friendly composite approach. Foams have bound-in polymeric phosphonate FRs, with added synergists and smoke suppressants. Such foams will not leach FR. Foams have fine cell structure and excellent flexible foam properties. Cone performance of the identified foam family (368 peak rate of heat release versus 1670 control – 78% reduction in PHRR)	Space Technology Mission Directorate	Kennedy Space Center

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			clearly surpasses that of standard commercial flexible PU foams: 502 to 913 for CAL 133 compliant foams, 953 for BS5852 compliant foam, and 1154 for CAL 117 compliant PU foam. Project foams easily comply with NASA 6001 open flame testing. Foams with under 3.0 pcf are available. Procedures for incorporation of significant Aerogel concentrations (5 pbw–15 pbw), useful for cryogenic and low temperature insulation, have been identified and tested. Results are based on over 200 foams made in small scale and 100 foams prepared as 5L molded foams. Phase II of Project involves scale-up of foams in the foam family, preparation of intermediate scale samples capable of more detailed application testing, performing such testing (e.g., cryogenic insulation testing), and sampling of foams to potential customers identified by the project expert Commercialization Panel. In working with foam vendors on intermediate scale sample preparation, potential commercial partners will be identified and assessed. Large scale runs are also planned. Potential commercial partners will have the opportunity to gain experience with the foams in intermediate scale sample preparation. Selected partners will have the opportunity to share their experience with the Commercialization Panel to focus on highest value applications and needed performance. Such interaction will lead to partnering, licensing and joint venture discussions.		
18078	NanoDrill: 1 Actuator Core Acquisition System, Phase II Project	Active	We propose to design, build, and test a sample acquisition drill weighing less than 1 kg. The drill uses a novel method of core or powder acquisition, and is suitable for both use by both robotic platforms and astronauts. The core acquisition bit can be used for either a rock core, icy-soil or loose regolith acquisition. The continued development of robust sample acquisition and handling tools is of critical importance to future robotic and human missions to Mars, the Moon, Asteroids, and other planetary bodies. For these missions, consolidated or unconsolidated core samples (as opposed to, say,	Space Technology Mission Directorate	Kennedy Space Center

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			scooped regolith or collected drill cuttings) are of particular interest. We will conduct testing in the laboratory and in the field to demonstrate the drill's effectiveness both in relevant environments, in relevant operational scenarios.		
17901	Particle Flow Physics Modeling for Extreme Environments, Phase II Project	Active	The liberation of particles induced by rocket plume flow from spacecraft landing on unprepared regolith of the Moon, Mars, and other destinations poses high mission risks for robotic and human exploration activities. This process occurs in a combination of “extreme environments” that combine low gravity, little or no atmosphere, rocket exhaust gas flow that is supersonic and partially rarefied, and unusual geological and mechanical properties of highly irregular surface regolith. CFDRC and the University of Florida will deliver unique plume driven erosion simulation software for such environments by combining novel granular physics simulation modules developed by UF with multi-phase gas-granular flow simulation software developed by CFDRC. Granular flow constitutive models, formulated through first-principle 3D Discrete Element Method particle kinetics and implemented in an efficient Eulerian gas-granular flow solver are the foundation of this software. The fidelity of these simulations will be advanced towards simulating particle compositions with broad shape and size variations. Novel particle kinetics modeling concepts will be applied to formulate granular flow physics models for both, realistic irregular particle shapes and dispersed particle size distributions. Phase I demonstrated the successful implementation and validation of irregular granular shape physics modeling in CFDRC's gas-granular multi-phase flow solver. An approach for extension to poly-disperse particle mixture simulations was also developed. Full integration of these models in Phase II will enable the simulation of gas flow interaction with poly-disperse, irregular shaped particle materials. Extensive verification, validation, and application demonstrations will	Space Technology Mission Directorate	Kennedy Space Center

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			be performed. The proposed technology development will result in unprecedented computer modeling capability for predicting liberation and flow of realistic granular material compositions in extreme extra-terrestrial environments.		
18917	Integrated Display & Environmental Awareness System Project	Active	Imagine you are an engineer or technician working on a critical space system and all the information you need is immediately available to you when you need it. All your work procedures, not just the ones you happened to have with you, are accessible on demand. You can quickly document your work with images and text without lifting a finger. Every move you make is recorded on demand and you can play it back later for training or analysis. For your particular task, you can immediately see exactly what others have done before you. Imagine having a telepresence capability that streams what you are seeing — as you see it — to colleagues anywhere in the world. In addition, all the emergency sensors and system health data is instantly available. When an emergency occurs, you find out immediately and further instructions are made available exactly when you need them. And all of this can be wirelessly transmitted across the globe or stored locally on your person. Now imagine all of this displayed and accessible right from your safety goggles using an embedded, lightweight wearable computer. The technology being proposed for this effort is a wearable computer with an optical head-mounted display providing various means of communication and augmented reality data to its user. Emerging wearable technologies are showing promise across many industries, from manufacturing to medical, yet there is minimal investment in the areas that specifically apply to NASA's unique mission. The wearable computer would allow users to have access to and modify critical information on a transparent, interactive display in their non-obstructed field of view without taking their eyes or hands off the work in front of them. The proposed technology would	Space Technology Mission Directorate	Kennedy Space Center

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			dramatically improve the user's situational awareness thus improving safety and efficiency. Once the technology is proven initially for ground operations, it can be transitioned for use in many other areas ranging from laboratory research to in-space mission operations, as well as to commercial manufacturing.		
33601	A Robust Architecture for Sampling Small Bodies, Phase I Project	Active	This proposal will develop an innovative architecture and concept of operations that permits reliable, safe, and repeated sampling of small bodies. The Lofted Regolith Sampling (LoRS) architecture is based on advanced astrodynamics and autonomy that is robust to target-body uncertainties and is adaptive during operations. The LoRS architecture is based on several key phases that ultimately lead to a thorough characterization of the target body and collection of multiple samples while avoiding complex and highly unpredictable landing requirements. The first phase of this characterization is the estimation of the body’s gravitational field and remote sensing of the NEO surface. After sufficiently characterizing the body, the second phase of the proposed architecture is to disturb material on the surface of the small body such that it is lofted into orbit about the body. This disturbance can be initiated with a variety of chemical explosions, kinetic impactors, or other forces which will be evaluated during the proposed effort. The third phase is to remotely characterize the lofted material to identify key attributes such as size and composition. The fourth phase of operations is for the orbiting spacecraft to approach a specific portion of the debris field and collect physical samples from the NEO. Once samples have been collected in orbit, the vehicle can further evaluate the samples onboard, identifying key constituents etc., and return this information to terrestrial scientists.	Space Technology Mission Directorate	Kennedy Space Center
33681	Green, Compact Hybrids for Nanosatellite	Active	Low-cost access to space is essential for continued commercial exploitation of near-Earth environments, and to support future science missions. A serious limitation on the cost of space access is the	Space Technology	Kennedy Space Center

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	Launchers, Phase I Project		available propellants and propulsion system technologies for launch, orbital insertion, maneuvering and orbital reinsertion, and reaction and attitude control. This Phase I STTR program will validate ignition and performance parameters for a volumetrically optimized, low cost, green, shippable hybrid propellant motor for low cost access to space. The program is specifically targeted at validating performance via fabrication and delivery of replacements for the current Nihka and PSRM-120 stages (stages 2 and 3) based on the Black Brandt sounding rocket vehicle testbed under the Nanolaunch 1200 program guidelines.	Mission Directorate	
32721	Telerobotic Perception during Asteroid and Mars Regolith Operations Project	Active	Current space telerobotic systems are constrained to only operating in bright light and dust-free conditions. This project will study the effects of difficult lighting and dust conditions on telerobotic perception systems to better assess and refine regolith operations on other neighboring celestial bodies. In partnership with Embry-Riddle Aeronautical University and Caterpillar, Inc., optical, LiDAR and RADAR sensing equipment will be used in performing the study. This project will create a known dust environment in the Swamp Works Granular Mechanics and Regolith Operations (GMRO) Laboratory regolith test bin to characterize the behavior of the sensing equipment in various calibrated lighting and dust conditions. It will also identify potential methods for mitigating the impacts of these undesirable conditions on the performance of the sensing equipment. Enhancing the capability of telerobotic perception systems will help improve life on earth for those working in dangerous, dusty mining conditions, as well as help advance the same technologies used for safer self-driving automobiles in various lighting and weather conditions. It will also prove to be a critical skill needed for advancing robotic and human exploration throughout our solar system, for activities such as mining on an asteroid or pioneering the first colony on Mars.	Space Technology Mission Directorate	Kennedy Space Center

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32729	Micro-scale Plasma Arc Gasification for Waste Treatment and Energy Production Project	Active	As NASA continues to develop technology for spaceflight beyond low earth orbit, we must develop the right systems for sustaining human life on a long duration or planetary mission. Plasma arc gasification (PAG) is an energy efficient mechanism of waste management for power generation and synthetic gas (syngas) production.	Space Technology Mission Directorate	Kennedy Space Center
32720	Self-Cleaning Boudouard Reactor for Full Oxygen Recovery from CO2 Project	Active	Oxygen recovery from respiratory CO_2 is an important aspect of human spaceflight. Methods exist to sequester the CO_2, but production of oxygen needs further development. The current ISS Carbon Dioxide Reduction System (CRS) uses the Sabatier reaction to produce water (and ultimately breathing air). Oxygen recovery is limited to 50% because half of the hydrogen used in the Sabatier reactor is lost as methane, which is vented overboard. The Bosch reaction is the only real alternative to the Sabatier reaction, but in the last reaction in the cycle (Boudouard) the resulting carbon buildup will eventually foul the nickel or iron catalyst, reducing reactor life and increasing consumables. To minimize this fouling, find a use for this waste product, and increase efficiency, we propose testing various self-cleaning catalyst designs in an existing MSFC Boudouard reaction test bed and to determine which one is the most reliable in conversion and lack of fouling. Challenges include mechanical reliability of the cleaning method and maintaining high conversion efficiency with lower catalyst surface area. The above chemical reactions are well understood, but planned implementations are novel (TRL 2) and haven't been investigated at any level.	Space Technology Mission Directorate	Kennedy Space Center
32426	Lunar CATALYST Project	Active	Lunar Cargo Transportation and Landing by Soft Touchdown (Lunar CATALYST) is a NASA initiative to encourage the development of U.S. private-sector robotic lunar landers capable of successfully delivering payloads to the lunar surface using U.S. commercial launch capabilities. NASA entered into no-funds-exchanged Space Act	Human Exploration and Operations	NASA Headquarters

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			Agreement (SAA) partnerships with three competitively-selected companies (Astrobotic Technology, Masten Space Systems, and Moon Express), and is providing in-kind contributions including technical expertise, access to test facilities, software, and the loaning of equipment.	Mission Directorate	
32947	Avionics and Software Project	Active	The goal of the AES Avionics and Software (A&S) project is to develop a reference avionics and software architecture that is based on standards and that can be scaled and customized. The architecture will contain basic core elements and functionality needed for any space–craft. The goal for specific mission implementation is that the avionics will be 80% core Avionics and Software elements and 20% unique. This project incorporates and builds on the results from the AES Avionics Architecture for Exploration and the Core Flight Software projects.	Human Exploration and Operations Mission Directorate	Johnson Space Center
32745	Gas House Autonomous System Monitoring (GHASM) Project	Active	This project involves the development of an autonomous monitoring system capable of assessing the condition of every element in the system, continuously and comprehensively. The Gas House Autonomous System Monitoring (GHASM) will be an intelligent knowledge system making inferences and conclusions on the state of system elements i.e., sensors, valves. Knowledge will be integrated across elements and subsystems to implement functional capabilities of an Integrated System Health Management (ISHM). These capabilities include (1) anomaly detection, (2) diagnostics, (3) prognostics, and (4) user interfaces to provide the operator with an integrated awareness about the system's health.	Space Technology Mission Directorate	Stennis Space Center
17558	Advanced Manufacturing Technologies (AMT): Additive Construction for Mobile	Active	As the nation prepares to return to the Moon, or journey on to Mars or to an asteroid, it is apparent that the viability of long duration visits with appropriate radiation shielding/crew protection hinges on the development of planetary surface structures, preferably in advance of a crewed landing, and preferably utilizing *in situ* resources. The Additive Construction with Mobile Emplacement (ACME) project will	Space Technology Mission Directorate	Marshall Space Flight Center

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	Emplacement Project		focus on the development of technologies to support automated development of *in situ* materials-based, planetary surface structures, including roads, berms, radiation, blast and micrometeoroid protection, and pressurized and un-pressurized structures. The Marshall Space Flight Center (MSFC) will team with Kennedy Space Center (KSC), Contour Crafting, Inc, (CCI), and the US Army Corps of Engineers (USACE) to execute this effort.		
18476	Ultra High Temperature Refractory Materials, Phase II Project	Active	Legacy refractory materials that have origins dating to the original Saturn program are commonly used in current launch facilities. Although they fail to meet the target requirements, they are the only approved material. Our research team has demonstrated a baseline system during the Phase I effort that combines a noncement binder, a high temperature macro aggregate, and reactive nano aggregates to produce an Ultra High Temperature Refractory (UHTR). Our UHTR system has sustained short-term exposures to 3000 C in a laboratory test and excellent resistance to environmental aging. The Phase II effort will optimize the mechanical and thermal behavior based on rocket plume exposure testing.	Space Technology Mission Directorate	Kennedy Space Center
32915	Life Support Systems Project	Active	The AES Life Support Systems (LSS) project is maturing Atmosphere Revitalization (AR), Water Recovery (WR) and Environmental Monitoring (EM) systems that will reduce risk, lower lifecycle cost, and validate operational process design and system architectural concepts for future human exploration missions. The project is maturing these technologies using the International Space Station (ISS) state-of-the-art hardware as a point of departure. The current life support systems on the ISS are a baseline from which to measure capability advancements for Environmental Control and Life Support System (ECLSS). By addressing technology gaps, LSS will be able to improve reliability of ECLS systems and advance them toward integrated testing here on Earth and on the ISS before the first human missions in the proving	Human Exploration and Operations Mission Directorate	Marshall Space Flight Center

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			ground of cis-lunar space. By focusing on a common core architecture with modular components, the LSS project promotes safe, affordable, and sustainable systems development. (This Project is a merger, beginning in FY2015, of the AES Atmosphere Resource Recovery & Environmental Monitoring for Long Duration Exploration Project (ARREM) Project and AES Water Recovery Project)		
33365	Innovative High Efficiency Filter for Mars Dust, Phase II Project	Active	NASA is developing methods to collect and convert local resources such as Martian air (mainly carbon dioxide, CO_2) into oxygen that can be used during the mission. The objective of this project is to protect such equipment from dust that may be sucked in with the CO_2. We proposed an innovative dust filtration system that is ideally suited for long duration operation in Mars because it works well in a low pressure environment and it is essentially self-cleaning. The system is based on two mechanisms of dust filtration that have been tested separately and successfully In Phase I. In Phase II, parametric tests will be performed with simulated Mars dust and under simulated Mars environment to optimize each mechanism. Then the two mechanisms will be combined in a prototype and tested. The prototype will be delivered to NASA for potential future tests in the zero-gravity airplane and in combination with the equipment to be protected.	Space Technology Mission Directorate	Kennedy Space Center
33358	Unmanned Solar Electric Resource Prospector, Phase I Project	Active	The proposed innovation is a spacecraft that could be used for lunar or asteroid prospecting missions. The mission plan would involve sending the spacecraft to an asteroid or other target, and analyzing the regolith for traces of water and other elements to be mined later for *in situ* resource utilization. The system features multiple innovations. One is game-changing high delta V solar electric propulsion (SEP) system featuring a hall thruster flowing iodine propellant. Another is a small tethered satellite with an on-board propulsion system that can be used as a modular working arm for the main spacecraft. The proposed Phase I program includes mission analysis, spacecraft, bus, and	Space Technology Mission Directorate	Kennedy Space Center

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			propellant module design, and identification of sensors and tools to be used for prospecting and plume analysis. Phase I also includes development of an iodine plasma spacecraft interactions model, which is a necessary precursor to any deep space mission with iodine propellant. In Phase II, the entire system including the spacecraft interactions model will be brought to a higher technology readiness level. Both Phase I and Phase II will include plasma plume measurements to support model development and analysis.		
32914	Logistics Reduction Project	Active	All human space missions, regardless of destination, require significant logistical mass and volume directly proportional to mission duration. As our exploration missions increase in distance and duration, reduction of these logistics requirements becomes even more important. Anything that can be done to reduce initial mass and volume of supplies or reuse items that need to be launched will be very valuable. Logistics are a subset of the habitation domain and has many interfaces with habitat life support and crew health systems. This project targets the best opportunities to demonstrate logistics reduction and repurposing. These technologies and innovations will make future exploration missions much more affordable. System engineering analysis using equivalent system mass (ESM) techniques are used in comparing the potential technologies for different exploration missions.	Human Exploration and Operations Mission Directorate	Johnson Space Center
18314	A high performance, electric pump-fed LOX / RP propulsion system, Phase II Project	Active	To date, the realization of small-scale, high-performance liquid bipropellant rocket engines has largely been limited by the inability to operate at high chamber pressures in a regeneratively cooled environment using on-board pumps for propellant pressurization. Ventions seeks to fulfill this critical need by using a novel fabrication scheme that builds on previously demonstrated technologies (under DARPA and NASA sponsored efforts) to design, fabricate and hot-fire test a pump-fed, 3,000 lbf LOX/RP propulsion system.	Space Technology Mission Directorate	Kennedy Space Center

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18365	Platform Independent Launch Vehicle Avionics with GPS Metric Tracking, Phase II Project	Active	For this award, Tyvak proposes to develop a complete suite of avionics for a Nano-Launch Vehicle (NLV) based on the architecture determinations performed during Phase I. This system will address the unique avionics challenges of a dedicated small launch vehicle and will use heritage and lessons learned from Tyvak's CubeSat avionics systems, modifying and optimizing its existing products for use with this new class of launch vehicles. The major technical objectives are: • Provide broad compatibility with all known NLV systems in development • Determine and provide appropriate performance and reliability metrics while maintaining the low-cost/low-mass approach made possible by commercial electronic systems • Implement the latest network protocols with support for wireless systems in the NLV environment • Develop a GPS metric tracking system and perform requirement verification to meet range safety recommendations • Demonstrate the reliability of low-cost/low-mass/low-power/redundant automatic flight termination system (AFTS) by combining the latest generation of commercial miniature GPS systems with high performance computer systems currently used by Tyvak– Validate functionality and performance for the entire NLV avionics suite through a series of incremental tests, from vibration and thermal vacuum, through a stratospheric balloon flight, an inert test article flight, to final demonstration on a NLV proxy.	Space Technology Mission Directorate	Kennedy Space Center
33560	ACE Booster, Phase II Project	Active	GTL has been developing a suite of transformational technologies that have the capability to disrupt the traditional launch vehicle paradigm. BHL composite cryotank technology provides a four times improve-ment over large aluminum iso-grid tanks, offering a 6 percentage point improvement in small stage PMF. Superior Stability Engine is an innovative liquid rocket engine configured to maximize combustion	Space Technology Mission Directorate	Kennedy Space Center

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			stability margin while also maximizing engine performance. NORPS is a nonhelium gas generator system that can be used to pressurize the propellant tanks for 1/3 the mass and 1/10 the volume of a comparable helium based system. Using these and other technologies, GTL has developed the conceptual design for the Advanced Cryogenic Expendable (ACE) nano-launch vehicle. The 7700 lb gross lift-off weight ACE vehicle is capable of delivering a 154 lb payload to 400 nmi circular orbit at 28.5 deg inclination. With a launch cost of less than $1M at low launch rate, ACE is directly competitive with existing large launch vehicles on a $/lb basis. This affordability is enabled by a combination of high performance, reduced stages and parts count, and simplified operations. The proposed Phase II effort will seek to reduce the ACE vehicle development risk by increasing the technology readiness level of critical technologies. Specifically, GTL will fabricate and test a prototype NORPS gas generator and pressurization system. Along with this, GTL shall fabricate a full-scale BHL composite cryotank for use in the system testing using modular manufacturing techniques. The integrated system shall be tested for operational capabilities to demonstrate the effectiveness of the technology and optimize the system design. The data from these tests will be used to refine and optimize the design of the ACE vehicle.		
34970	Resource Prospector Project	Active	Resource Prospector (RP) is an ISRU capability demonstration activity currently planned to launch in 2020. Expanding human presence beyond low-Earth orbit to asteroids and Mars will require maximum possible use of local materials — so-called *in situ* resources. If selected for flight, RP would be a first effort to validate prospecting, extraction, and analysis of planetary surface resources for the express purpose of resource utilization. RP will be able to find water (in the form of ice or hydrated minerals), extract it, process it and store it. In addition to ISRU validation, RP would be able to characterize the distribution of	Human Exploration and Operations Mission Directorate	Ames Research Center

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			water and other volatiles at the lunar poles, enabling future innovative uses of local resources. The knowledge gained by RP should also be useful for exploring near-Earth asteroids and Mars, and could reduce the overall risks of human exploration. Through the RP demonstration, NASA may be able to determine if lunar resources can be harvested to support future deep space missions.		
34165	Subsurface Prospecting by Planetary Drones, Phase I Project	Active	The proposed program innovates subsurface prospecting by planetary drones to seek a solution to the difficulty of robotic prospecting, sample acquisition, and sample characterization at multiple hazardous locations in a single mission. Innovation focuses on a specific, challenging scenario: subsurface access of multiple lava tubes by drones far enough from Earth for speed-of-light latency to preclude direct human control. The technology will be broadly applicable to resource prospecting in cold traps, dark craters, cryovolcanoes, asteroids, comets, and other planets. The technology is also applicable to Earth-relevant problems such as the detection of poisonous and explosive gases and flammable dust in mines; and surveying urban canyons; exploring bunkers and caves. The proposed innovation is the development of Anytime Motion Planners that can generate feasible guidance routines to accomplish subsurface prospecting by planetary drones. Anytime Motion Planners are algorithms that can quickly identify an initial feasible plan, then, given more computation time available during plan execution, improve the plan toward an optimal solution. In addition to Anytime Motion Planners, optimal guidance routines will also be innovated in this work by formulating the Generic Autonomous Guidance Optimal Control Problem (Problem G&C) (Pavone, Acikmese, Nesnas, and Starek, 2013) as a convex optimization problem and employing interior-point methods to solve the resulting problem to global optimality. This work will determine whether	Space Technology Mission Directorate	Kennedy Space Center

TechPort ID	Item Title	Status	Abstract	Responsible Mission Directorate	Lead Center or Facility
			optimal solutions may be computed quickly enough to be useful in practice.		
34187	The World is Not Enough (WINE): Harvesting Local Resources for Eternal Exploration of Space, Phase I Project	Active	The paradigm of exploration is changing. Smaller, smarter, and more efficient systems are being developed that could do as well as large, expensive, and heavy systems in the past. The “science” fiction becomes reality fueled by advances in computing, materials, and nano-technology. These new technologies found their way into CubeSats – a booming business in the 21st century. CubeSats are no longer restricted to aerospace companies. Universities and even High Schools can develop them. The World is Not Enough (WINE) is a new generation of CubeSats that take advantage of ISRU to explore space for ever. The WINE takes advantage of existing CubeSat technology and combines it with 3D printing technology and a water extraction system developed under NASA SBIR, called MISWE . 3D printing enables development of cold gas thrusters as well as tanks that fit perfectly within the available space within the CubeSat. The MISWE allows capture and extraction of water, and takes advantage of the heat generated by the CubeSat electronics system. The water is stored in a cold gas thruster's tank and used for propulsion. Thus, the system can use the water that it has just extracted for prospecting to refuel and fly to another location. This replenishing of propellants extends the mission by doing ISRU (living off the land) even during the prospecting phase. In Phase 1, we plan to test and investigate critical technologies such as (1) sample acquisition, (2) volatiles capture, and (3) 3D-printed cold gas thrusters that use water vapor including the organic and particulate contaminants that are inevitable during the early stages of asteroid mining. The engine is similar to a Solar Thermal Engine but scaled for a CubeSat. In Phase 2, we propose to develop a testbed of the critical systems and to demonstrate these onboard the International Space Station (ISS).	Space Technology Mission Directorate	Kennedy Space Center

TechPort ID	Item Title	Status	Abstract	Responsible Mission Directorate	Lead Center or Facility
88195	Voluntary Consensus Organization Standards for Nondestructive Evaluation of Aerospace Materials (including Additive Manufactured Parts) Project	Active	This NASA-industry effort accomplishes the following: (1) Lead collaboration between NASA Centers, other government agencies, industry, academia, and voluntary census organizations (ASTM Committees E07 on Nondestructive Testing, F42 on Additive Manufacturing (AM) Technologies, and ISO Technical Committee (TC) 261) to develop national standards for NDE of aerospace materials used in NASA/aerospace applications. (2) Lead a leveraged interlaboratory study (ILS) to develop NDE for qualification and certification of AM parts. (3) Lead ASTM E07 development and periodic revision of flat panel polymer matrix composite (PMC) standards: ASTM E2533 (Guide) [1], E2580 (ultrasonic testing (UT) [2], E2581 (shearography) [3], E2582 (flash thermography) [4], E2661 (acoustic emission) [5], E2662 (radiographic testing (RT)) [6], and draft work item WK40707 (active thermography). (4) Lead periodic revision of composite overwrapped pressure vessel (COPV) standards: E2981 (overwrap) [7] and ASTM E2982 (liner) [8]. (5) Develop a new NDE of AM Guide (ASTM WK47031) [9]. (6) Develop a new eddy current test (ECT)-UT-profilometer standard practice or test method for fracture control of metal parts using 90/95 Probability of Detection (POD) of critical initial flaws sizes in metal parts (TBD). (7) Respond to NASA Office of Safety and Mission Assurance (OSMA) and NASA Space Technology Mission Directorate (STMD) requests as needed (e.g., AM, advanced manufacturing, counterfeit parts and ESA/JAXA collaboration). The historical standards development time line (Items 3 through 6) is shown in Figure 1. The WK47031 effort (Item 5) constitutes the bulk of the present focus and capitalizes on momentum created by the release of the FY2014 Nondestructive Evaluation of Additive Manufacturing State-of-the-Discipline Report (NASA-TM-218560) [10]. The ultimate goal vis-à-vis WK47031 is to	Office of Safety and Mission Assurance	White Sands Test Facility

TechPort ID	Item Title	Status	Abstract	Responsible Mission Directorate	Lead Center or Facility
			determine the effect-of-defect of specific seeded flaw types while determining detection thresholds using controlled embedded features. A portion of this effort also dovetails with the NASA Engineering and Safety Center (NESC) Universal ECT-UT-Profilometer Scanner project.		
34056	Free-Flying Unmanned Robotic Spacecraft for Asteroid Resource Prospecting and Characterization, Phase II Project	Active	In Phase 2 we will develop a fully integrated, autonomous free-flying robotic system based on a commercial SkyJib quadcopter, and demonstrate flying straight and level to a target location, acquisition of rock and regolith samples, and return to the point of origin. The work plan for Phase 2 is as follows: (1) Completion of the Guidance, Navigation, Control, Vision, and Sample Acquisition subsystems. (2) Integration of all the payload elements at ERAU and system level check out. (3) Demonstration of the entire system at NASA KSC. (4) Field deployment at analog location.	Space Technology Mission Directorate	Kennedy Space Center

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APPENDIX 3. REFERENCES

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APPENDIX 4. ABBREVIATIONS AND ACRONYMS

3D	three-dimensional
ABRS	Advanced Biological Research System
AES	Advanced Exploration Systems
AO&M	autonomous operations and maintenance
APH	Advanced Plant Habitat
ARMD	Aeronautics Research Mission Directorate
BRIC	Biological Research in Canisters
CCAFS	Cape Canaveral Air Force Station
CIF	Center Innovation Funds
CIR	Combustion Integrated Rack
CO2	carbon dioxide
CRADA	Cooperative Research and Development Agreement
CTC	Core Technical Capability
DRM	Design Reference Mission
ECLSS	Environmental Control and Life Support System
EDL	entry, descent, and landing
EMC	Evolvable Mars Campaign
GEO	geosynchronous orbit
GSDO	Ground Systems Development and Operations
HEDS	Human Exploration Destination Systems
HEO	high-Earth orbit
HEOMD	Human Exploration and Operations Mission Directorate
HLHS	Human Health, Life Support, and Habitation Systems
IRAD	Innovation Research and Development
ISRU	*in situ* resource utilization
ISS	International Space Station
ISSP	International Space Station Program
JAXA	Japan Aerospace Exploration Agency
KFT	Kennedy Fization Tubes
Kg	kilogram
KSC	Kennedy Space Center
LC	Launch Complex
LCH_4	liquid methane

LED	light-emitting diode
LEO	low-Earth orbit
LH_s	liquid hydrogen
LO_2	liquid oxygen
LRR	Logistics Reduction and Repurposing
LSP	Launch Services Program
MARCO POLO	Mars Atmosphere and Regolith COllector/PrOcessor for Lander Operations
mmscf	million standard cubic feet
NASA	National Aeronautics and Space Administration
NEO	near-Earth object
NIAC	NASA Innovative Advanced Concepts
NRA	NASA Research Announcement
NSPIRES	NASA Solicitation and Proposal Integrated Review and Evaluation System
O&M	operations and maintenance
OCT	Office of the Chief Technologist
PAR	Photosynthetically Active Radiation
PI	Principal Investigator
ppe	personal protective equipment
R&T	Research and Technology
RASSOR	Regolith Advanced Surface Systems Operations Robot
RaTS	Research and Technology Studies
REDDI	Research, Development, Demonstration, and Infusion
RESOLVE	Regolith and Environment Science and Oxygen and Lunar Volatile Extraction
RTMB	Research and Technology Management Board
SBIR	Small Business Innovation Research
SCaN	Space Communications and Navigation
SLPS	Space Life and Physical Sciences
SLS	Space Launch System
SMD	Space Mission Directorate
SMT	Systems Maturation Team
SSP	Space Solar Power
SSTIP	Strategic Space Technology Investment Plan
STIP	Strategic Technology Investment Plan
STMD	Space Technology Mission Directorate
t	tonnes

TA	Technology Area
TABS	Technology Area Breakdown Structure
TAP	Technology Advancing Partnership
TPS	Thermal Protection System
TRL	Technology Readiness Level
TtG	Trash to Gas
TTO	Technology Transfer Office
USDA	United States Department of Agriculture
X-Hab	eXploration HABitation

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